EUROPEAN PARLIAMENT

STOA

Scientific and Technological Options Assessment

POSSIBLE TOXIC EFFECTS FROM THE NUCLEAR REPROCESSING PLANTS AT SELLAFIELD (UK) AND CAP DE LA HAGUE (FRANCE)

A first contribution to the scientific debate

1.) Introduction: Letter to the reader by the Chairman of the STOA Panel on the decision taken by the Panel on 23 October 2001

2.) Study by WISE - Paris

3.) Evaluation reports by experts

Luxembourg, November 2001

Directorate General for Research

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3. EVALUATION REPORTS BY EXPERTS

EXECUTIVE SUMMARY AND GENERAL CONCLUSIONS

1. Introduction

The principal aim of this report is to assist the Committee of Petitions of the European Parliament in its consideration of Petition 393/95 brought by Dr. W. Nachtwey. The Petition expresses concerns about radioactive discharges from nuclear reprocessing plants at Sellafield in the UK and La Hague in France, and their possible adverse health effects. Six years after the Petition was introduced, the Petitioner's main concerns remain relevant. This report concludes that reprocessing discharges are a valid matter for the Committee's consideration. It also concludes that, on balance, the Petitioner's concerns over radioactive discharges from Sellafield and La Hague are justified.

The report presents evidence and data on:

- radioactive discharges from the Sellafield and La Hague sites;
- resulting nuclide concentrations in environmental media including foodstuffs;
- radiation doses from nuclide discharges to critical groups near the sites;
- adverse health effects near the two sites; and
- resulting collective doses from nuclide discharges.

The report also examines a number of current issues in radiobiology concerning health effects from exposure to ionising radiation, in particular genetic and in utero effects.

In addition, in accordance with contract specifications, the report examines other major factors that might influence future decision-making on reprocessing. It provides information on the legal framework, the operational history of the plants and the economic case for reprocessing compared with available alternatives for spent nuclear fuel management. The report also makes policy-related recommendations that take into account current knowledge and uncertainties in risk assessment and the availability of alternatives to reprocessing in spent fuel management.

2. Reprocessing Status and Issues

Only 5% to 10% of world annual spent fuel arisings is submitted for reprocessing, with the rest stored pending final disposal in a repository. The largest centres in the world for commercial reprocessing remain Sellafield in the UK and La Hague in France. Reprocessing involves the dissolution of the spent fuel in boiling concentrated nitric acid and subsequent physico-chemical separations of uranium and plutonium. Multiple waste streams are created by these physical and chemical processes. While some wastes are retained and conditioned, considerable volumes of liquid and gaseous wastes are released to the environment. Reprocessing operations release considerably larger volumes of radioactivity than other nuclear activities, typically by factors of several 1,000 compared with nuclear reactors.

3. International and European Legal Framework

The report provides a brief overview of Major International Bodies that play a role in the development of international nuclear standards and the main International Conventions relative to nuclear reprocessing are presented.

The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, to which the European Commission is a Contracting Party, is of particular relevance to reprocessing activities. The OSPAR Commission has declared its commitment to the application of the precautionary principle, the polluter-pays principle, and to the application of Best Available Techniques (BAT) and Best Environmental Practice (BEP), including, where appropriate, Clean Technology. At the Sintra Meeting in 1998, Ministers agreed to reduce marine pollution "*with the ultimate aim of achieving concentrations in the environment*

near background values for naturally occurring substances and close to zero for man-made synthetic substances." They emphasised the importance of the Precautionary Principle in this work. It is notable that the commitment is to achieve concentrations in the environment close to zero, not merely concentrations in discharges. At the Copenhagen Meeting in June 2000, the OSPAR Commission voted unanimously (with the abstentions of the UK, France and the European Commission) that discharge authorisations be reviewed *"with a view to, inter alia: implementing the non-reprocessing option (for example dry storage)."*

The Euratom Treaty provides the basis for the European regulation of the nuclear sector. Article 34 requires Member States to obtain the opinion of the European Commission before they carry out *"dangerous experiments."* According to the Commission, France has not requested the Commission's opinion under Article 34 concerning activities in La Hague nor has the UK as regards activities in Sellafield.

↙ Conclusions on "Dangerous Experiments"

The Member States UK and France apparently have not complied with Article 34 of the Euratom Treaty, since they have never requested the European Commission's opinion under the article concerning any of their activities at Sellafield and La Hague.

Article 35 of the Euratom Treaty grants control rights to the European Commission for the verification of operation and efficiency of monitoring equipment at nuclear facilities. However, only one verification mission was carried out at Sellafield (1993) and La Hague (1996). These are considered to be outdated. Furthermore, the Commission is apparently highly dependent on information provided by Member States. It is equally doubtful whether the Commission is in a position to determine, as required under Article 37, whether the reprocessing activities are liable to result in the radioactive contamination of the water, soil or airspace of another Member State. In addition to the dependence on Member States' information, the Commission spends only extremely limited manpower into the evaluation of nuclear projects (2 person-months in the case of reprocessing plants).

↙ Conclusions on European Commission Responsibilities under Article 35 of the Euratom Treaty

The Commission's verification activities make ineffective use of its control rights over monitoring equipment. Statements by the Commission on monitoring at Sellafield and La Hague are not backed up by credible data. It is noted, however, that the Commission is currently reviewing its verification activities.

The Commission is apparently not in a position to guarantee that the Basic Safety Standards are respected concerning the La Hague and Sellafield facilities and to determine whether the reprocessing activities are liable to result in the radioactive contamination of the water, soil or airspace of other Member States.

4. Risk Assessment of Radioactive Releases

Radioactive discharges from both sites are very large and indeed rank among the largest anthropogenic sources of radioactivity to the world. As such they constitute a reasonable subject for enquiry by the Committee. Nuclides released to air and sea result in the contamination of food chains via a number of pathways. Individuals may also receive radiation doses from immersion in radioactive aerosols, inhalation of radioactive gases and particulate matter, and ground shine from nuclides deposited on land.

Various computer models have been designed to estimate radiation doses from nuclide releases to members of critical groups living near nuclear facilities. These calculated doses are used to regulate discharges from nuclear facilities.

However, this approach protects individuals and not populations. The use of collective doses has therefore been stipulated by various international bodies, including the European Commission in the Basic Safety Standards Directive (96/29). Crucial theoretical underpinning for collective dose was provided by the scientific community's adoption of the Linear No-Threshold model for radiation's adverse health effects. This states that there is no level of radiation exposure below which there is no effect: risks continue with declining doses until zero dose. Even the smallest possible dose, i.e. a photon passing through a cell nucleus, carries with it a risk of cancer. Although this is an extremely small risk, it is still a finite risk.

Collective dose estimates strongly depend on the size of the population considered and the time scale used. Opinions vary as to which populations and time scales should be used. Given the very long term half-lives of

some radionuclides released by reprocessing plants (e.g. iodine-129, 16 million years) and their global distribution, there should be no time limits and dose evaluations should be global. There is no reason why future generations or distant populations should be any less protected than current generations in the vicinity of the facilities.

Comparisons of doses from nuclear activities with those induced by natural background radiation are flawed because, inter alia, these omit to indicate the health impact of background radiation itself. It has been estimated that natural background radiation results in about 6,000 to 7,000 UK cancer deaths per year in the UK with a similar figure for France.

↙ Conclusions on Dose Estimates

In order to evaluate the risk of large releases of radionuclides into the environment, in addition to critical group dose estimates, collective dose calculations should be carried out and taken into account during decisions on the continued operation of reprocessing plants.

5. Case Study Sellafield

Between 1965 and the end of year 2000, about 26,000 tonnes of spent gas graphite fuel were reprocessed by the B205 line at Sellafield. About 3,000 tonnes of spent light water reactor fuel have been reprocessed at THORP since 1994. Based on current contracts and annual throughput rates, both plants are expected to shut down within the next 10 years or earlier.

Although gaseous releases of most nuclides from Sellafield have not varied to a marked extent since the 1970s, iodine-129 emissions have increased 10-fold. Radioactive marine releases of carbon-14, strontium-90 and caesium declined markedly in the early 1980s, while in the mid 1990s increases occurred in releases of carbon-14, cobalt-60, strontium-90, technetium-99 and iodine-129. Over the same period, actinide (mainly plutonium) discharges have declined markedly.

Internal BNFL documents suggest significant increases in nuclide releases in the future at Sellafield. For some *"worst case"* scenarios, the operator predicts for *"levels approaching or above the limits"* for sea discharges of over half the currently authorised radionuclides. A similar situation is expected for aerial releases.

↙ Conclusions on Sellafield Releases

Increases of releases of key radionuclides from Sellafield in the late 1990s and expected future discharges are inconsistent with obligations under the OSPAR Convention.

The deposition of plutonium within 20 km of Sellafield attributable to aerial emissions has been estimated at 160-280 GBq (billion becquerels), that is two or three times plutonium fallout from all atmospheric nuclear weapons testing. In addition, significant quantities of radionuclides can become airborne in sea spray and be transported inland by the wind. The average activity due to actinides from the sea may occasionally exceed the international limit of 1 mBq/m^3.

It has been estimated that over 40,000 TBq (trillion becquerels) of caesium-137, 113,000 TBq of beta emitters and 1,600 TBq of alpha emitters have been discharged into the Irish Sea since the inception of reprocessing at Sellafield. This means that between 250 and 500 kilograms of plutonium from Sellafield is now adsorbed on sediments on the bed of the Irish Sea. The migration of undersea deposits of actinides to coastal environments represents a long-term hazard of largely unknown proportions.

Technetium-99 (half-life 214,000 years) discharges have led to particular concern. In 1997, technetium concentrations in crustacean – particularly in lobster – reached 13 times the European Council Food Intervention Level (CFIL) in the vicinity of Sellafield. Some technetium concentrations above CFIL limits have also been found in molluscs (winkles, mussels, limpets and whelks). Recent environmental surveys along the Norwegian coast indicate a six-fold increase in technetium concentrations in seaweed since 1996. Concentration factors are greater than 1,000 for some biota such as macrophytic brown algae, worms and lobsters and are particularly high for some seaweeds (around 100,000). In 1999, a number of high

concentrations of various radionuclides were also recorded in fish, shellfish, sediments and aquatic plants, some exceeding CFILs several times. Large uncertainties remain in the field of transfer of technetium in the biosphere.

↙ Conclusions on Radionuclide Concentrations in the Sellafield Environment

Marine discharges at Sellafield have led to significant concentrations of radionuclides in foodstuffs, sediments and biota. Discharges lead to current concentrations in some foodstuffs, which exceed European Community Food Intervention Levels (CFILs). The transfer of technetium to the biosphere is of particular concern, because of its long half-life (214,000 years), its mobility in seawater and the high concentration factors in plants. Large uncertainties remain as to the transfer mechanisms and environmental fates of many radionuclides.

During the 1970s and 1980s, peak doses to critical groups in the Sellafield region possibly reached 2.5 to 3.0 mSv per year (as compared to a dose constraint of 0.3 mSv in the UK and 1 mSv in the EU). Latterly, doses to marine-related critical groups have declined to about 0.2 mSv per year.

A recent study commissioned by the German Federal Office for Radiation Protection, using German statutory dose assessment assumptions, calculated that annual doses from consumption of contaminated foodstuffs were more than 5 times the annual limit imposed by the European legislation and about 20 times the annual dose constraint used in the UK and Germany. Most of the dose was received via the technetium contaminated seaweed fertiliser/animal feed/meat consumption pathway. The conclusion of the German study was that the Sellafield reprocessing facilities would not be "licensable" in Germany. European legislation does not prescribe specific assumptions in dose assessment models. The European Commission has responded that *"the guidance currently being produced on realistic dose assessments will comment on this issue."*

↙ Conclusions on Doses Induced by Sellafield Discharges

Discharges to the Sellafield marine environment have led in the past to doses to critical groups exceeding 10 times current UK and 3 times EU limits. The doses calculated by the UK administration from current environmental radionuclide concentrations reach respectively 2/3 and 1/5 of the UK and EU limits. These doses remain problematic, considering that doses from past discharges and from direct radiation are ***not*** included. Doses calculated under German statutory dose assessment assumptions exceed UK and EU dose constraints. In addition, German dose limits for organs (also used in the US but not in the rest of the EU) would also be exceeded by the ingestion of relatively small quantities of seafood from Sellafield. The Sellafield reprocessing plants would not be licensable in Germany. Also very large uncertainties in dose estimates remain, with differences between 5th and 95th percentiles often exceeding several orders of magnitude. This raises the question of whether "realistic" assessments should be used rather than "conservative" dose assessments.

The risk potential of certain hazards at Sellafield is very large. Liquid high level wastes currently stored at Sellafield contains about 7 million TBq (2,100 kg) of caesium-137, which is about 80 times the amount released through the 1986 Chernobyl accident. Assuming a 50 percent release of caesium-137 in an accident at Sellafield, population dose commitment would range up to tens of millions of person-Sv resulting in over a million fatal cancer cases.

↙ Conclusions on Hazards Posed by Liquid High Level Waste at Sellafield

The hazard potential of liquid high level wastes in particular is very high. A serious accident might lead to large releases of radioactivity and on the long term globally to over one million fatal cancer cases.

Higher incidences of childhood leukaemia than expected were first identified near Sellafield in 1983. The cause or causes of the observed increases in childhood leukaemia near Sellafield have not been determined, nor is it known whether a combination of factors is involved. The UK Committee on the Medical Aspects of Radiation in the Environment (COMARE) has stated: *"As exposure to radiation is one of these factors, the possibility cannot be excluded that unidentified pathways or mechanisms involving environmental radiation are implicated."*

Various hypotheses, including paternal preconception irradiation and population mixing have been advanced without being conclusive. Possible explanations for the discrepancy between observed cancers and estimated low doses include erroneous dose assessments (in particular foetal doses) and uncertainties as to the parameter of "dose" and what it measures.

Besides childhood leukaemia, other areas of concern have arisen, including reports of increased incidence of retinoblastoma in children and a statistically significant increase in stillbirth risk in the Sellafield region.

↙ Conclusions on Health Effects from Reprocessing at Sellafield

More than fifteen years of research has established that the excess incidence of childhood leukaemia around Sellafield is statistically significant and is continuing. The cause or combination of causes of the observed leukaemia increases are not known. Many uncertainties remain. Radiation exposure due to radionuclide releases from Sellafield cannot be excluded as a cause for the observed health effects.

6. Case Study La Hague

Between 1966 and the end of 2000, about 21,000 tonnes of spent fuel have been reprocessed at La Hague. Most waste generated at La Hague has remained unconditioned – in other words they were not stabilised and packaged for long term or permanent storage – for many years, and some is stored under very unsatisfactory safety conditions, including over 9,000 m^3 (or 39,000 containers equivalent) of plutonium contaminated sludge.

In 1999, the total radioactivity released by La Hague to the environment was 15,000 times higher than that released by a nearby nuclear reactor. While releases of some radionuclides (e.g. technetium-99, plutonium) have decreased or remained constant, releases of other radionuclides from La Hague have significantly increased over the past decade. These include liquid discharges (iodine-129 x 5; tritium x 3) as well as gaseous releases (carbon-14 x 8; krypton-85 x 5; tritium x 3). Also, some important radionuclides are not measured at all, including chlorine-36, technetium-99, and strontium-90 aerial emissions.

↙ Conclusions on La Hague Releases

Releases of radioactivity from La Hague to the environment are several orders of magnitude larger than releases from a nuclear reactor. Releases of some radionuclides have decreased in the past while liquid and gaseous discharges of other key radionuclides have increased significantly. A further group of radionuclides is not being measured in effluents. Increases of radioactive releases from La Hague in the 1990s and expected future discharges are in violation of obligations under the OSPAR Convention.

There have been numerous accidents at La Hague, some involving significant radioactive releases. For example, as a consequence of a severe discharge pipe break in 1980, doses to individuals of the critical group (fishermen) exceeded the annual EU limit of 1 mSv by 3.5 times. Main potential hazards at La Hague are linked to the risk of fires and explosions in the storage pools, in the vitrification plants or in the effluent treatment plants, and to the risk of dispersion of the caesium-137 stocks in the spent fuel pools, or of the separated plutonium stocks.

↙ Conclusions on Accidental Releases from La Hague

Past accidents at La Hague include at least one accident that led to population doses significantly exceeding EU limits. Accidents are estimated to be responsible of 36% of the leukaemia risk level for the 0-24 year age category around the La Hague site. The hazard potential of the La Hague spent fuel stores is very large. The accidental release of a fraction of the caesium inventory in the cooling pools could cause up to 1,5 million fatal cancers.

Concentrations of most of the nuclides measured in samples taken in the La Hague environment reached their peak during the 1980s. Nuclide concentrations have decreased on average unequally, depending on nuclides and samples, by factors between 5 and 50 if compared to 1997 levels. These developments do not reflect the large increases in releases of some radionuclides (in particular tritium, iodine-129 and carbon-14). However, there is a notable lack of complete series of data and redundant measurements. Occasionally, there have been samples taken that exceed EU Community Food Intervention Levels (CFILs), in particular in

crabs. While most of the samples are taken and measured by operators, it is remarkable that the highest readings were obtained by independent measurements.

↙ Conclusions on Radionuclide Concentrations in the La Hague Environment

Radionuclide concentrations in the La Hague environment have generally decreased since the 1980s. However, a comprehensive trend analysis is difficult or impossible because of lacking data on some key radionuclides. The sampling and analysis should be significantly extended in order to guarantee redundancy and a thorough analysis of the impact of the large increases in releases of some radionuclides during the 1990s.

Calculated doses from routine radionuclide releases of the La Hague reprocessing plant generally remain small and well within the EU limits. However, the uptake of radioactivity taken into account in critical group scenarios is very small and can be reached with very small amounts of higher contaminated foodstuffs. Doses can increase accordingly through the consumption of such foodstuffs. The cumulative effective doses induced by the consumption of seafood, as calculated under German statutory dose assessment assumptions, significantly exceed German and EU dose constraints. It is questionable whether the current French practice of dose assessment can be considered conservative.

↙ Conclusions on Doses Induced by La Hague Discharges

Calculated doses from routine releases at La Hague generally remain well within EU limits. However, doses calculated under German statutory dose assessment assumptions exceed German and EU dose constraints. The La Hague reprocessing plants would not be licensable in Germany. The current French dose assessment practices do not appear to be conservative.

In 1983, morbidity was found to be higher than expected in the greater La Hague area for men in case of leukaemia and respiratory organs, and for women in case of leukaemia and lung cancer. Moreover, mortality data show an increased rate of cancers for the digestive organs in the Department. In 1995, a study identified an excess of leukaemia cases among persons aged 0-24 years living in the canton about 10 km from the La Hague plant. In 1997 case control study, the authors claimed “convincing” evidence for a causal role in childhood leukaemia for environmental radiation exposure from recreational activity on beaches and fish and shellfish consumption.

In 1999, the GRNC (Groupe Radio-écologique Nord-Cotentin) reported that the contribution to doses from nuclear facilities was low, as regards the increased incidence of leukaemia revealed in earlier epidemiological studies. While GRNC calculated individual doses up to six times higher than the operator values, these did not exceed 6% of the EU annual limit. The report stated that the result was an average estimate and that uncertainty margins were not quantified. The quantification of these uncertainties is currently underway.

In June 2001, a new study confirmed earlier findings on leukaemia in the La Hague region. The study indicated that the increased incidence was continuing, and provided more data to allow statistical significance to be established for the increases in leukaemia in the La Hague area.

↙ Conclusion on Health Effects around La Hague

A statistically significant increase in the incidence of leukaemia in the La Hague area has been established. This increase is continuing. There is, as yet, no conclusive evidence for a causal link to radioactive releases from La Hague. However, these cannot be ruled out as a factor contributing to the health effects observed.

The assessment of doses and their effects are surrounded by many uncertainties. These include errors in assumptions on parameters, errors in computer codes, measurement errors and paucity of environmental monitoring. GRNC has identified more than 4,000 parameters, including 200 critical parameters, in its methodology to assess dose impact.

On the question of iodine-129 releases, WISE-Paris has quantified the differences between the theoretical activity in spent fuel and the activity discharged to sea and air. Large gaps are observed in the beginning of the 1990s, as only 50% of the theoretical values were reported discharged. In the worst case, the committed collective dose from non-attributed iodine-129 in the period 1989-1999 would be about the magnitude of a

serious nuclear accident such as the Windscale fire (Sellafield) or the Kyshtym (Russia) waste explosion in 1957.

The Precautionary Principle is clearly laid down in various binding international agreements (e.g. Agenda 21, EC Treaty). In 1992, Agenda 21 pointed out that radioactive wastes are among *"the contaminants that pose the greatest threat to the marine environment."* The Earth Charter of March 2000 calls notably to *"place the burden of proof on those who argue that a proposed activity will not cause significant harm, and make the responsible parties liable for environmental harm."*

↙ Conclusions on Uncertainties and the Precautionary Principle

Many uncertainties remain regarding dose assessments. In addition, error margins may be large and might modify assessed doses significantly. Under these conditions, the continued release of large quantities of radionuclides into the environment from Sellafield and La Hague violates the Precautionary Principle.

7. Comparative and Cumulative Analysis

Differences exist in effluent treatment between Sellafield and La Hague. Carbon-14 which is the major contributor to collective doses, for example, is partially removed from air emissions at Sellafield while all of it is released at La Hague. Its abatement is not considered cost effective by Cogema.

In 1999, a representative year, releases from La Hague and Sellafield were broadly comparable. In general terms, La Hague discharges were marginally greater than those from Sellafield, except for iodine-129 and tritium air emissions and technetium-99 liquid discharges.

Until 1992, Sellafield and La Hague released a total of some 1.2 tonnes of iodine-129 to the environment. This is several hundred times that released at Chernobyl. In the period 1993-1998, a further 1.7 tonnes of iodine-129 were discharged (of which 80% from La Hague). Iodine-129 discharged from La Hague and Sellafield in 1999 alone was eight times greater than that released by the fallout from all nuclear weapons testing.

↙ Conclusions on Comparative and Cumulative Analysis

In 1999, radioactive releases to the environment from La Hague and Sellafield were broadly comparable. Iodine-129 discharged from La Hague and Sellafield that year was eight times greater than the total iodine-129 released by the fallout from all nuclear weapons testing.

The estimated global collective dose of a decade of radioactive releases from Sellafield and La Hague (77,000 manSv) corresponds to about 1/7 of the collective dose from the Chernobyl accident, or to a Kyshtym scale accident every year. This raises the question of the justification of these releases as required under the radiological principles of the International Commission on Radiological Protection.

Also, in conventional cost-benefit studies, monetary values are attributed to a human life. When applied to untruncated global doses from 10 years' of Sellafield and La Hague releases, very large sums are obtained (£ 1.8 and 5.9 billion – respectively 2.9 and 9.4 billion Euro): the amounts that therefore could be spent on abatement measures comfortably exceed annual operating profits at each site.

8. Alternative Options

↙ Conclusions on Alternative Options

Non-reprocessing options, and available dry storage technologies in particular, are considerably less expensive than reprocessing. In addition, their social and political acceptability are much greater than reprocessing. Nuclear utilities are increasingly moving towards dry storage solutions, including utilities in the US, Canada, Germany, Russia and many eastern European countries. Direct disposal options also significantly reduce waste volumes to be disposed, due to the large volumes generated by reprocessing.

General Conclusions

The reprocessing of spent nuclear fuel at Sellafield (UK) and at La Hague (France) leads to the largest man-made releases of radioactivity into the environment worldwide. The releases correspond to a large-scale nuclear accident every year. Some of the radionuclides released in great quantities have half-lives of millions of years. Concentrations identified in recent years in the environment repeatedly exceeded EU Community Food Intervention Levels (CFILs).

The discharge trends through the 1990s towards large increases in the releases of certain key radionuclides at Sellafield and La Hague and further planned increases in releases constitute a violation of letter and spirit of the OSPAR Convention.

Accidental radionuclide releases from Sellafield and La Hague could be by two orders of magnitude larger than in the case of the Chernobyl disaster and could lead globally over the long term in both cases to over one million fatal cancers.

The European Commission does not effectively use its verification rights. The Commission is highly dependent on information provided by Member States and is therefore apparently not in a position to guarantee that the Basic Safety Standards are respected concerning the La Hague and Sellafield facilities. It is doubtful whether the Commission is in a position to determine whether the reprocessing activities are liable to result in the radioactive contamination of the water, soil or airspace of another Member State.

Operational and/or accidental releases from Sellafield and La Hague have led in the past to population doses that exceed current EU limits. Reprocessing alone accounts for about 80% of the collective dose impact of the French nuclear industry. In the UK, about 90% of nuclide emissions and discharges from the UK nuclear programme result from reprocessing activities.

In the surrounding regions of Sellafield and La Hague a statistically significant increase in the incidence of leukaemia has been established. While research on the causal relationship with environmental radiation has not been conclusive, it cannot be ruled out that exposure to radiation is an initiating or at least a contributing factor.

There are great uncertainties involved in the assessment of doses to populations and subsequent health effects. The release of large quantities of long lived radionuclides at Sellafield and La Hague therefore violates the Precautionary Principle, laid down, inter alia, in the European legislation, Agenda 21 and the Earth Charter of March 2000.

1. INTRODUCTION

1.1. OBJECTIVE OF THE STUDY

The principal aim of this report is to assist the Committee of Petitions of the European Parliament in its consideration of Petition 393/95 brought by Dr. W. Nachtwey. The Petition expresses concerns about radioactive discharges from nuclear reprocessing plants at Sellafield in the UK and La Hague in France, and their possible adverse health effects (see summary of the Petition at ***Annex 1***).

The reprocessing of spent nuclear fuel involves its dissolution and the chemical separation of uranium and plutonium. As spent fuel remains extremely radioactive and, as many radioactive waste streams are created by these chemical processes, reprocessing results in significant radioactive releases to atmosphere and sea.

The original rationale for reprocessing was the recovery of fissile plutonium for nuclear weapons. This has declined and officially is no longer a reason for continued reprocessing in the UK and France. Other rationales, including recovery of plutonium for breeder reactors and mixed oxide fuel, have declined or remained static in recent years. As a result, the frequency of new reprocessing contracts is declining. In world terms, most (>80%) spent fuel arisings are stored rather than reprocessed: new developments concern storage rather than reprocessing technologies.

The nuclear fuel cycle involves a number of steps from uranium mining and milling, through enrichment, fuel fabrication, reactor operations, spent fuel storage, radioactive waste conditioning and final disposal. Some nuclear operators have chosen to reprocess rather than store and condition their spent fuel. The single step of reprocessing emits considerably more radioactive discharges than all other steps combined. Reprocessing discharges from Sellafield and La Hague rank among the largest anthropogenic discharges of radioactivity throughout the world, and constitute a reasonable subject for enquiry by the Committee.

Controversy exists over the reprocessing of spent nuclear fuel: views are polarised and strongly held by proponents and opponents. The Governments of Member States UK and France continue to support reprocessing activities in their countries, despite declining public enthusiasm according to opinion polls in the UK, and despite protests from other Member States. In recent years, doubts over waning rationales for reprocessing have been raised by some government and industry officials and by politicians of various political parties, even in the UK and France. The Committee will be aware that continued reprocessing within the European Union is, to a major extent, a political rather than scientific matter.

As requested by STOA, this report concentrates on the effects of reprocessing discharges on health, safety and the environment. In particular, this report presents evidence and data on :

- radioactive discharges from the Sellafield and La Hague sites;
- resulting nuclide concentrations in environmental media including foodstuffs;
- radiation doses from nuclide discharges to critical groups near the sites;
- adverse health effects near the two sites; and
- resulting collective doses from nuclide discharges.

The report examines a number of current issues in radiobiology concerning health effects from exposure to ionising radiation, in particular genetic and in utero effects.

In addition, in accordance with contract specifications, the report examines other major factors that might influence future decision-making on reprocessing. It describes the legal framework, the operational history of the plants and the economic case for reprocessing compared with available spent fuel management alternatives. The report does not examine mixed oxide fuel (MOX) matters in detail, as these would require a separate study.

The report also makes a number of conclusions and policy-related recommendations that take into account the current knowledge and uncertainties on risk issues and of the availability of alternatives to reprocessing in spent fuel management.

1.2. BACKGROUND AND CHRONOLOGY OF THE PROJECT

Petition n° 393/95 was introduced by Dr. W. Nachtwey and a group of 22 senior citizens from Hamburg, Germany, in February 1995. The petitioners raised concerns over the radioactive pollution of the North Sea and the Atlantic Ocean due to the operation of nuclear reprocessing facilities at Sellafield (UK) and La Hague (France). The present study project, as requested by the Committee of Petitions, was included in the Year 2000 Work Plan adopted by the STOA Panel on 17 February 2000. It was subsequently approved by the Bureau of the European Parliament on 1 March 2000.

Although Petition n° 393/95 has its origin in an initiative by individuals, it reflects widespread concern in many countries about radioactive discharges and the incidence of radiation-induced illnesses near facilities discharging radioactive matter. For example, concerns over the levels of radioactive contamination from Sellafield and La Hague discharges have been expressed by international and regional bodies, including Agenda 21 and OSPAR meetings.

Within individual countries, the public has also expressed concern about the local impact of reprocessing facilities on environment and health. This has led to initiatives by national authorities to assess corresponding risks, including studies by COMARE (Committee on Medical Aspects of Radiation in the Environment) in the UK, and by GRNC (Groupe Radioécologie Nord-Cotentin) in France. Some Member States (Denmark, Ireland) and countries close to the EU (Norway) have protested for many years over continued reprocessing at Sellafield and La Hague.

Concerns over reprocessing discharges have also resulted in a growing number of studies exploring the risks which may be associated with large-scale nuclide discharges, including raised incidences of childhood leukemias near both reprocessing facilities. So far, no consensus has emerged on whether radioactive discharges have caused the increased incidences of leukemia, even although at least one recent study involved representatives from both industry and environmental groups. Six years after the Petition was introduced, the Petitioner's main concerns remain relevant. Therefore the prime objective of this study has been to examine the *"possible toxic effects from the nuclear reprocessing plants"*, and derive concrete Policy Options according to the specifications of the contract.

A Scoping Meeting was held in Brussels on 24 January 2001. The co-ordinator of the project presented a Scoping Paper for the study. Only one comment on the Scoping Paper (by the Petitioner) had been received prior to the meeting. A Scoping Meeting Report was delivered on 27 February 2001 that notes that while *"there was no basic disagreement with the content of the Scoping Paper and the methodology presented by Mr. Schneider on the basis of the contract with STOA, there has been some concern that health and environmental issues will get appropriate attention in the study."*

An Interim Report was presented to the STOA Panel on 10 April 2001. The report reflected the current work in progress, and at that stage was felt not satisfyingly balanced between the different parts to be analysed. The co-ordinator of project enlarged the project team in response to the remarks by the STOA Panel and associated two additional experts in the field of radiation effects, Dr. Fairlie and Dr. Sumner, to the team. The focus of the present report reflects the views of the STOA Panel expressed at the earlier meetings.

The Interim Report also contained a set of proposed Policy Options, taking into account the specific roles of major actors in this area. These include the *nuclear industry* at operational level, the *national governments* for their key role in decision making on spent fuel management (UK and France but also other Member States), the *European Commission*, which has powers of supervision and regulation of nuclear activities in the EU, and finally the *European Parliament* for its legislative and overview roles. The Parliament's roles include the protection of the populations against industrial risks, but also decision-making procedures, public information and participation, independent auditing and decisions on EU institution budgets. The proposed Policy Options were submitted for comments to MEPs and to some experts. The Policy Options presented in this final report take into account comments received.

In the process of the research, the authors have formally consulted, inter alia, the European Commission (DG Environment, Radiation Protection Unit), the French national Institut de Protection et de Sûreté Nucléaire IPSN (the Director of Protection and Chairperson of the Radioecological Group Nord-Cotentin), the DRIRE (Regional Division of Industry, Research & Environment) of the La Hague region. The authors also consulted informally with many other organisations and individuals, particularly in the UK. The co-ordinator wishes to thank all those who contributed to this project.

2. REPROCESSING STATUS AND ISSUES

2.1. NUCLEAR REPROCESSING

The reprocessing of spent nuclear fuel has been carried out since the 1950s in a number of countries to retrieve fissile plutonium, originally for weapons purposes. Reprocessing has been also carried out by a few other countries in small amounts for fuel purposes (e.g. Japan and India). However clearly the largest centres in the world for commercial reprocessing remain Sellafield in the UK and La Hague in France.

The United Nations [UNSCEAR, 2000] has stated that only *"about 5% to 10%"* of world spent fuel arisings is submitted to reprocessing: the rest is stored pending final disposal in a repository. The number of countries relying on reprocessing to deal with their spent fuel has been declining [IAEA, 1999].

The reprocessing of spent nuclear fuel involves its dissolution in boiling concentrated nitric acid and subsequent physico-chemical separations of uranium and plutonium. Multiple waste streams are created by these physical and chemical processes. These waste streams include releases from fuel storage ponds, dissolver units, solvent treatment plants, HLW (liquid) processes and tanks, ILW processes and tanks, LLW processes, off-gas treatment plants, and liquid scrubber plants [Homberg, 1997].

As spent fuel contains high levels of radioactivity, discharges from reprocessing are correspondingly radioactive. Most fission product releases and plutonium releases from the UK and French nuclear programmes result from their respective reprocessing activities. It will be seen below that, apart from reductions in discharges of a few radionuclides, discharges and emissions from the two facilities have not decreased over the past few decades and indeed, in the case of some nuclides, have increased.

Reprocessing operations release considerably larger volumes of radioactive discharges than other nuclear activities, typically by factors of several 1,000 compared with nuclear reactor discharges. According to a European Commission report [CEC, 1995] produced by the Centre d'Étude sur l'Évaluation de la Protection dans le domaine Nucléaire (CEPN, a research agency essentially funded by CEA and COGEMA), reprocessing alone accounts for about 80% of the collective dose impact of the French nuclear industry. In the UK, Fairlie [1997] has estimated that about 90% of nuclide emissions and discharges from the UK nuclear programme result from reprocessing activities.

2.2. ORIGINS OF REPROCESSING

Uranium-fuelled reactors produce plutonium in their nuclear fuel during normal operation. The main fissile plutonium isotope, plutonium-239, is produced through neutron capture by the uranium isotope uranium-238. As stated above, the main purpose of reprocessing is to retrieve plutonium from spent fuel. Plutonium is a man-made element, which exists only in trace amounts in nature. In France and the UK, bulk quantities of weapons plutonium were produced in the first generation of nuclear power plants, and separated from spent fuel initially in dedicated reprocessing plants.[1]

Early in the development of nuclear technology, plutonium became of particular interest to the nuclear power industry. The establishment of breeder reactor technology became a major goal. The basic concept was fascinating: plutonium generated as by-product in first-generation, uranium-fuelled nuclear reactors would be separated, incorporated into fuel assemblies, and re-introduced into second-generation breeder reactors that would produce more plutonium than they consumed. In this manner, the lifetime of uranium reserves would be greatly extended. Decision-makers were impressed by this concept, and research & development funds were distributed generously. In fact, the first reactor to produce electricity was the US Experimental Breeder Reactor EBR-1, in 1951.

[1] The name "plutonium factory" (usine de plutonium, UP) given by the French to its plutonium separation facilities may be more apposite than the term "reprocessing plant".

By the early 1970s, the major nuclear countries had breeder programs under way. France commissioned the 250 MWe Phenix in 1973 and the UK the Prototype Fast Reactor (PFR) in 1974. During the same period, the European 1,200 MWe Superphenix project was launched. In 1977, the head of the French Atomic Energy Commission (CEA) predicted the operation of 540 large breeder reactors in the world by the year 2000.

To supply plutonium for the expected fleet of breeders, the European nuclear establishment launched large-scale reprocessing plant projects in the 1970s. After the first international project, the reprocessing plant EUROCHEMIC in Belgium, failed because national projects received higher priority, utilities chose to have their spent fuel reprocessed in France at La Hague and in the UK at Sellafield. Between 1976 and 1979, following a first series of smaller agreements, contracts were signed for the reprocessing of some 7,000 tonnes of spent fuel at each plant, UP3 and THORP. These reprocessing contracts have been mostly completed between 1990 and 2000. Utilities from EU Member States Belgium, France, Germany, Netherlands, Sweden and the UK, plus Japan and Switzerland, signed up to those contracts.[2]

Two decades later the situation has changed radically. Massive new uranium ore sources[3] have been found – much greater than had been expected. Consequently the prices of natural uranium have been falling from one historical low to another. Breeder programs, which proved more expensive and less technically successful than anticipated, have been shelved. Germany abandoned its completed SNR-300 reactor at Kalkar in 1991 before it started up. The plant was turned into an amusement park. The UK shut down its PFR in 1994. The world's only commercial-size breeder reactor, Superphénix in France, was shut down in 1996 after achieving a lifetime load factor of 6.3% (actual electricity generation as a fraction of the theoretical maximum).

However plutonium production programs were not modified in response to these developments. Large reprocessing plants at Sellafield and La Hague were put into operation between 1989 and 1994 as if nothing had changed. As a result, large stockpiles of plutonium, reprocessed uranium and reprocessing wastes continue to build up in both countries. The impacts of reprocessing should be viewed within a broad context. Reprocessing does not occur in isolation, but as an element of a country's wider political policies. The social costs and benefits of reprocessing should be analysed accordingly.

In recent years, the plutonium industry put forward MOX fuel (plutonium-uranium mixed oxide fuel) as a rationale for continued reprocessing. These claims, like reprocessing itself, are the subject of conflicting views. This report refrains from examining MOX issues in detail as these lie outside its remit. However it is noteworthy that the maximum anticipated MOX fuel use, i.e. about 200 tonnes per year, is small in comparison with the 11,000 tonnes of uranium fuel used each year.

Also in recent years, proponents of reprocessing have stated that it continues to offer utilities a method of managing their spent fuel stocks. This report discusses the safer and less expensive alternative of medium-term dry storage. However it is noted that, in some cases, decisions by different utilities on spent fuel management differ widely for reasons which appear to have more to do with policy and belief than technical necessity or commercial considerations. These attitudes are often not amenable to rational discussion.

2.3. IMPLICATIONS OF REPROCESSING

Reprocessing is one option among various spent fuel management options. In the year 2000, the volume of spent fuel reprocessed was about a sixth of the spent fuel generated worldwide: most reprocessing occurs at La Hague and Sellafield. As can be seen from this low fraction of spent fuel reprocessed, most utilities operate their nuclear power plants without reprocessing and plutonium use. Therefore this report's examination of reprocessing does not imply any comment on nuclear power programmes.

Differences of view exist between Member States of the European Union on reprocessing. Views on continued reprocessing remain polarised between different groups within Member States, and within European Union bodies. Consequently, nuclear reprocessing remains a highly politicised subject, on which a consensus may be difficult to achieve.

[2] Swedish utilities eventually subcontracted their shares in the reprocessing agreements to other utilities but remained, formally, as contracting parties.

[3] In Kazakhstan, Uzbekhstan and Canada particularly.

3. INTERNATIONAL AND EUROPEAN LEGAL FRAMEWORK

3.1. INTERNATIONAL LEGISLATION AND TREATIES

Although the regulation of nuclear energy remains the responsibility of national authorities, the fact that nuclear-related activities have potential transboundary impacts, has brought the international community to take on the elaboration of some common standards. A list of the main texts is presented in the ***Annex 2***.

3.1.1. Major International Bodies

International and regional organisations have played a major role in the development of nuclear standards.

- ***The International Commission on Radiological Protection(ICRP)***

  International action in the field of radiation protection standards started with the establishing of the International Commission on Radiological Protection (ICRP). The ICRP was founded in 1928 (and reconvened after the II. World War in 1950) by the International Society of Radiology as its commission on international issues. The main committee of the ICRP, 13 members, voted in by co-optation, provides recommendations and guidance on all aspects of the protection against ionising radiation that is turned into a legal framework by most of the countries in this world.

- ***United Nations Committee on the Effects of Atomic Radiation(UNSCEAR)***

  The United Nations Committee on the Effects of Atomic Radiation (UNSCEAR) was established in 1955 by the United Nations to evaluate doses, effects and risks from ionising radiation on a world wide scale following growing concerns over potential effects from nuclear weapons testing. Most of the standards elaborated by international and regional organisations such as Euratom and the International Atomic Energy Agency (IAEA) are based on the research undertaken by the ICRP and UNSCEAR.

- ***The International Atomic Energy Agency(IAEA)***

  The United Nations International Atomic Energy Agency, IAEA, is primarily an inter-governmental forum for scientific and technical co-operation (and promotion) in the nuclear area. The IAEA today counts 130 Member States. The Agency provides its Member States with guidance and standards as a complementary element to national criteria and regulations when the latter are not based on other existing international conventions.

- ***OECD Nuclear Energy Agency (NEA)***

  The Nuclear Energy Agency (NEA) is a semi-autonomous body within the Organisation for Economic Co-operation and Development (OECD). The Agency provides assistance to its Member countries in developing scientific and legal bases for the safe use of nuclear energy. The NEA counts 27 Member States, representing *"85% of the world installed nuclear capacity."*

3.1.2. Major International Conventions

The international legal framework in the nuclear sector is composed of legally binding agreements and recommendatory standards. Among the most important international conventions on radioactive material management that have contributed to the development of the international legal framework in the nuclear sector one may cite:

- ***The Convention on Nuclear Safety***

  It entered into force on 24 October 1996. The Convention commits the signatories to ensure the safety of civil nuclear power plants including the storage, handling and treatment of radioactive materials.

- ***The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management***

  It was open for signature in September 1997. Within the framework of this agreement, the parties must take the necessary measures to ensure the safe and environmentally sound management of radioactive waste and spent fuel.

A large number of bilateral and multilateral agreements have also dealt with safety standards and regulations in the nuclear sector, particularly in the field of marine pollution.

While major international conventions have referred to the necessity to prevent marine pollution from nuclear activities, for instance Agenda 21 (June 1992) and the Earth Charter (June 2000), others were specifically devoted to this matter, notably:

- ***The Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter– "London Dumping Convention"***

  It was signed on 29 December 1972. Aiming at improving the protection of the marine environment, the Convention encourages *"States, with a common interest in particular geographical areas, to enter into appropriate agreements"* to promote the effective control of all sources of pollution. In particular, it prohibits the dumping of wastes if not duly authorised and controlled by the Member States' authorities.

- ***The Convention for the Protection of the Marine Environment of the North-East Atlantic – "OSPAR Convention"*** (see also ***Chapter 3.2*** and ***Annex 3***)

  It was opened for signature at the Ministerial Meeting of the Oslo and Paris Commissions in Paris, on 22 September 1992. The Convention has been signed and ratified by all of the Contracting Parties and it entered into force on 25 March 1998. It defines general guiding principles to deal with the problem of pollution, from land-based sources notably (Annex I of the OSPAR Convention), such as the precautionary principle; the polluter pays principle and best available techniques (BAT) and best environmental practice (BEP), including clean technology. It also provides for the OSPAR Commission, established by the Convention, to adopt binding decisions.

3.1.3. The European Legal Framework And Its Implementation

The basis of European law is established in the European Community Treaties. In particular, the majority of legislation dealing with nuclear activities is found in the Euratom Treaty, signed in Rome on 25 March 1957.

In addition to Council Directive 96/29/Euratom, there are a number of other directives and regulations relating to specific activities within this sector, which deal with the different issues, among which:

- health and safety at work (Radiation Protection of Outside Workers, Council Directive 90/641/EURATOM);
- transport of radioactive substances (Shipments of Radioactive Waste, Council Directive 92/3/EURATOM);
- and shipments of Radioactive Substances, Council Regulation (Euratom) No. 1493/93.

The main documents applying are listed in the ***Annex 4***.

3.1.3.1. Euratom Treaty

The Treaty Establishing the European Atomic Energy Community (Euratom Treaty) lays the foundation for the Community regulation in the nuclear sector. Other relevant legislation can also be found in the EEC Treaty and supplement and the Single European Treaty.

European legislation does not provide for a control of the Member States' national procedures leading to the granting of authorisations of releases of radioactivity to the environment.

As a primary legislative instrument, the Euratom Treaty imposes obligations on the Member States under Articles 33 to 37 concerning notably the monitoring of the environment and the disposal of wastes.

• Application of Article 34

Article 34 states: *"Any Member State in whose territories particularly dangerous experiments are to take place shall take additional health and safety measures, on which it shall first obtain the opinion of the Commission. The assent of the Commission shall be required where the effects of such experiments are liable to affect the territories of other Member States."*

The Commission declared that: *"France has not requested the Commission's opinion under Article 34 of the Euratom Treaty concerning activities on La Hague nor has the UK as regards activities in Sellafield."*[4] Given the number of previously untested activities carried out at La Hague and Sellafield, it is extremely surprising that there has not been a single request by the operators for opinion under Article 34. In fact, there has never been a single request for a Commission Opinion by the UK (unclear for France). The oral explanation given by the Commission[5] that the original aim of the article was to cover peaceful nuclear explosions – that were never carried out in the EU – is not satisfying. The legal analysis of the non-application of Article 34 would go beyond the scope of this study but seems to be absolutely indispensable.

• Application of Article 35

Article 35 is the strongest legal basis for the implementation of an efficient control mechanism of nuclear installations in the EU. It states: *"Each Member State shall establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards. The Commission shall have the right of access to such facilities; it may verify their operation and efficiency."*

The Basic Safety Standards for the protection of health of the general public and workers against the danger of ionising radiation are laid down in the Directive (80/836) of 15 July 1980. These standards were revised in the Euratom Directive (96/29EURATOM) of 12 May 1996.

European Commission verification activities provided for in Article 35 are very limited due to resource constraints: *"Since the re-launch of the verification activities in 1990 the Commission has performed verification visits at the Sellafield site on 6-10 December 1993 and at the La Hague site on 22-26 July 1996. Each verification visit is normally performed by 4 inspectors, who carry out checks on the operation of instruments for environmental monitoring and follow the data chain for a number of randomly chosen samples from sampling through to transmission of the final results to the competent authorities. The quality assurance system is also checked. The Article 35 of the Euratom Treaty verification activities are currently being reviewed by the Commission."* [6]

The Commission has commented on the issue on a number of occasions in answers to parliamentary questions. One of those answers stated: *"The installations which were the object of this check are primarily those which have a direct impact on the environmental radioactivity level… The equipment for monitoring gaseous and liquid effluents from these establishments was also checked as part of the assessment of their impact on the environment"*. Parliament and other Member States are forwarded, on request, *"the main comments formulated by the Commission."* The Council and the Parliament are periodically provided with a report summing up *"the progress made with its programme of checks."* [7]

During a meeting with the Co-ordinator of the present study[8] and in a subsequent letter[9] the Commission has clarified a certain number of points:

• The Commission has repeatedly made reference to the *"re-launch"* or the *"resumption"* of Article 35 verification activities. However, the term is based on oral information about some earlier verification activities that would have been carried out in the 1960s. No written evidence exists within the Commission

[4] Stephen Kaiser, Head of Radiation Protection Unit, Commission of the European Communities, e-mail to Mycle Schneider dated 10 May 2001.

[5] Meeting between Stephen Kaiser and four other representatives of the unit with Mycle Schneider, Luxembourg, 17 May 2001.

[6] European Commission, Answer to Question n°46 by MEP Nuala Ahern, 14 June 2001.

[7] Answer given by Mrs Wallström on behalf of the Commission (31 March 2000) to question E-0477/00 by Hiltrud Breyer (Verts/ALE) to the Commission (24 February 2000, OJ C 330 E, 21/11/2000 (p. 170)).

[8] Meeting in Luxembourg, 17 May 2001, op. cit.

[9] Stephen Kaiser, Commission of the European Communities, e-mail to Mycle Schneider dated 12 June 2001.

services to back up that information. The Commission representatives exclude that La Hague – military significance – or Sellafield – the UK joined the EC later – were amongst these potential verifications in the 1960s.

• In 1990, the Commission planned to carry out about 60 verifications per year. The goal was to inspect each facility in the EU on average about once every five years and major facilities like reprocessing plants every two years. In reality, only two to three verifications have been carried out per year and in total 20 verifications have been carried out in the 10 year period between October 1990 and December 2000. Only two are planned for 2001. The main reason indicated by the Commission are of budgetary nature.

• The Commission considers that the conclusions reached at the verifications at Sellafield in 1993 and La Hague in 1996 *"with respect to arrangements for monitoring environmental radioactivity could be expected to be broadly the same. There have however been developments, particularly at Sellafield (e.g. start of operation of THORP and EARP) that did not operate at the time of the visits."* During the meeting in Luxembourg the Commission representatives clearly stated what that means: the verification, particularly at Sellafield but also at La Hague, is *"out of date."*

• The Commission stated that *"although compliance with the requirement to assess and limit doses is a Member State responsibility, the Commission does have a significant amount of information available to it on this matter. These data indicate that, in general, the radiation doses received by the public are a small fraction of the dose limits and that the maximum credible range of uncertainties would not compromise respect of this limit. The Commission is aware of the circumstances under which dose limits to the public might be exceeded and is vigilant in taking a proactive approach to verify compliance."*

• Member States consider, as stated by Michael Meacher, Minister for the Environment in the UK, that *"under Article 35 of the Treaty the European Commission has the right of access to certain facilities. The Article does not require submissions to be made to the Commission."* [10]

The Commission was not in a position to supply the STOA Study Team with copies of the verification reports on Sellafield and La Hague because they *"fall under the exemptions to access provided for under the access policy and that there is therefore no entitlement to see them."* However, the Commission informed the STOA Study Team that it has *"asked the UK and France if they would agree to the reports being released to you."* [11] As of the end of July 2001, the Study Team had not received any answer on the issue from the Commission.

However, the STOA Study Team in the mean time found out that a copy of the 1993 Sellafield Verification Report had been placed in the Library of the UK House of Commons. The 29 page report (plus tables) is a stunning indication of the superficial nature of the Article 35 verification exercise:

- The preparatory documents referenced were essentially of statistical nature.

- The four person verification team had a huge visiting programme during a three and a half day presence at Sellafield and in the surrounding area, including visits of the BNFL ship *Seascan*, of a laboratory in Whitehaven, witnessing demonstrations of measurements in the environment and of collection of winkles, visiting a dairy farm, an air sampler at Calderbridge and at least seven stacks besides a *"conducted tour of the disposal site"* at Drigg.

- The introduction to the report states that *"given the complexity of the facilities, the purpose of the review was not to undertake a systematic verification of all of the aspects but to provide an overview of the system with a number of spot checks limited by the time available"* and *"while only part of the discharge monitoring facilities could be verified, their selection was representative for the overall surveillance programme, thus allowing to draw general conclusions on its adequacy."* However, the report fails to justify the methodology and the representative nature of its verification activities.

- The general conclusion (less than 1 page of text) states that the team *"observed the proper functioning of a representative subset of stack monitoring equipment"* and that any controlled ground level aerial releases are *"properly accounted for"* and that the overall arrangements *"ensure that aerial releases*

[10] Written reply to question by Llewelyn Smith, dated 11 May 2001.
[11] Stephen Kaiser, Commission of the European Communities, e-mail to Mycle Schneider, dated 10 May 2001.

and their environmental impact are well controlled" and finally that discharges to the sea are *"adequately monitored."*

- The report is of exclusively descriptive nature. It does not contain any analysis, nor any discussion (for example of error margins or technical and conceptional uncertainties), nor any kind of criticism. The verification team obviously found the situation at Sellafield perfect.

The STOA Study Team considers that the Commission's activities carried out under Article35 are obviously not appropriate to make effective use of its control rights of monitoring facilities and "verify their operation and efficiency." Statements by the Commission on the appropriate nature and efficiency of such monitoring facilities at Sellafield and La Hague are not backed up by credible data.

Furthermore, the Commission is apparently highly dependent on information provided by Member States and is therefore apparently not in a position to guarantee that the Basic Safety Standards are respected in the Member States and concerning the La Hague and Sellafield facilities in particular.

• Application of Article 37

Since 1979, the Commission has issued three opinions concerning La Hague within the framework of Article 37 of the Euratom Treaty that requires that *"each Member State shall provide the Commission with such general data relating to any plan for the disposal of radioactive waste in whatever form as will make it possible to determine whether the implementation of such plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State."*

The Commission gives its Opinion after consulting a group of experts. Article 37 is completed by the Commission Recommendation 1999/829/Euratom of 6 December 1999 which defines the data to be transmitted to the Commission and the time limits to be respected.

As an illustration, the Commission Opinion concerning the nuclear fuel reprocessing plants UP3 and UP2–800 of the La Hague Establishment was issued according to the following procedure:

• On 1 March 1989, reception of *"the general data concerning the plan for the disposal of radioactive waste"* transmitted by the French authorities. The general data is not available from the Commission as it is considered confidential with the Member States.

• On 8 June 1989, meeting of the Group of Experts set up pursuant to the Treaty, in Cherbourg. The experts required further complementary information.

• On 20 July 1989, the Commission concluded in its Opinion on the La Hague facilities that: *"the implementation of the plan for the disposal of radioactive waste from the UP3 and UP2-800 plants at the La Hague Establishment is not liable, either in normal operation or in the case of an accident of the type and magnitude considered in the general data, to result in radioactive contamination, significant from the point of view of health, of the water, soil or airspace of another Member State; however, in certain severe accidental circumstances, significant levels of contamination might be obtained in the Channel Islands, but the projected doses could be reduced at non-significant levels by the introduction of countermeasures."*

The selection of reference accidents is made by the national authorities and *"it is not in the intention of the Commission or the experts to impose specific reference accidents. Nevertheless, it is the responsibility of the Commission and the experts to consider if the accidents taken into consideration are those which are of importance for the type of installation concerned, as regard the frequency and the potential for major release."* [12]

The loss of cooling to a High Active Liquor feed vessel was considered as a reference accident in the case of Sellafield. As regards the La Hague (UP3 and UP2-800) submission, the reference accident taken into consideration was the loss of cooling in the concentrated fission products vessels.

At Commission level, *"the estimated number of man-months spent to analyse the General Data and to draft the Report of the Group of Experts and the Commission's Opinion is about 2 for reprocessing."* [13] The

[12] Stephen Kaiser, Commission of the European Communities, e-mail dated 12 June 2001.
[13] Augustin Janssens, Commission of the European Communities, e-mail dated 3 May 2001.

Commission managed to present its Opinion in less than five months after the submission of the General Data by France. Considering the difficulty in co-ordinating a Group of Experts of over 40 people, not to speak about the time necessary to countercheck a significant amount of complex data and review additional input from the experts, two man-months over four and a half month period seems a very small time budget.

It is highly questionable whether the Commission under these conditions is in a position to fulfil its obligation under Article 37 *"to determine whether the implementation of such plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State."* ***The Opinion expressed by the Commission appears to excessively rely on the General Data submitted by the Member States. This reliance is not being adequately expressed in the various generally re-assuring statements made by the Commission on the impact of the facilities at Sellafield and La Hague.***

3.2. MARINE POLLUTION - APPLICATION OF THE PRECAUTIONARY PRINCIPLE

While the marine environment is sometimes treated as convenient sink, or even as interesting laboratory (see ***Annex 5***), international conventions have repeatedly justified the application of the precautionary principle, especially for discharges of radioactive effluents into the sea, as a means to respond to uncertainty.

In 1992, Agenda 21 put forward the characteristics of radioactive wastes to call for a safe and environmentally sound management, *"including their minimisation, transportation and disposal"* (Chapter 22). It clearly pointed out that radioactive wastes are among *"the contaminants that pose the greatest threat to the marine environment."*

The signatories were called upon to *"support efforts within IAEA to develop and promulgate radioactive waste safety standards or guidelines and codes of practice as an internationally accepted basis for the safe and environmentally sound management and disposal of radioactive wastes"* (Chapter 22).

Highlighting the fact that there was *"no global scheme to address marine pollution from land-based sources"*, Agenda 21 called on nations to *"commit themselves to control and reduce degradation of the marine environment to maintain and improve its life-support and productive capacities"*, the aim being to *"anticipate and prevent further degradation of the marine environment and reduce the risk of long-term or irreversible effects on the oceans"* (Chapter 17).

In its Section II. Ecological Integrity, Paragraph 6, the Earth Charter of March 2000 called on nations to *"Prevent harm as the best method of environmental protection and, when knowledge is limited, apply a precautionary approach:*

a. *Take action to avoid the possibility of serious or irreversible environmental harm even when scientific knowledge is incomplete or inconclusive.*
b. *Place the burden of proof on those who argue that a proposed activity will not cause significant harm, and make the responsible parties liable for environmental harm.*
c. *Ensure that decision making addresses the cumulative, long-term, indirect, long distance, and global consequences of human activities.*
d. *Prevent pollution of any part of the environment and allow no build-up of radioactive, toxic, or other hazardous substances.*
e. *Avoid military activities damaging to the environment."*

The London Dumping Convention of 1972, in which the signatories convened to *"promote the effective control of all sources of pollution of the marine environment"* (Article 1), gave an impulse to international co-operation some twenty years later with the conclusion of the OSPAR Convention. The latter considered that additional international actions aiming at preventing and avoiding marine pollution had to be taken as part of a progressive and coherent program for the protection of the sea.

The OSPAR Convention required the application of the precautionary principle by *"taking every possible measure"* to prevent and eliminate pollution and protect the maritime zone against prejudicial effects of human activities (Article 2). The French authorities, nevertheless, consider that the OSPAR Convention defines only *"general obligations, such as the prevention and elimination of pollution with the application of the precautionary and the polluter-pays principles"* notably. Further detailed decisions taken within the

framework of the OSPAR Convention *"commit only the Member States which voted them."* [14] There is a risk that such decisions remain unapplied as long as they are not signed by France and Great Britain.

In 1999, the OSPAR Commision defined the following strategy regarding radioactive substances :

"-by the year 2000

a. the Commission will, for the whole maritime area, work towards achieving further substantial reductions or elimination of discharges, emissions and losses of radioactive substances;

-by the year 2020

b. the Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero."

The decision adopted in June 2000 (and which came into force in January 2001) concerning discharges in relation with reprocessing compels the signatories to review *"as a matter of priority"* the authorisations for radioactive discharges from reprocessing plants, and work towards *"implementing the non-reprocessing option."* The United Kingdom and France, although they refused to sign the decision, are politically obliged to comply with the orientation defined by the Commission. Similarly, the Sintra Declaration signed in July 1998, calling for near zero-level discharges of liquid radioactive substances by the year 2020, is much more a plea for a common political will to protect the environment than a legally-binding instrument.

The matter therefore should clearly be addressed at European level in application of Article 174(2) of the EC Treaty: *"Community policy on the environment shall be (…) based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay."*

[14] P. Saint-Raymond, Assistant Director of DSIN, in "La Convention OSPAR et les rejets radioactifs dans l'Atlantique", *Contrôle*, n° 137, November 2000.

4. RISK ASSESSMENT OF RADIOACTIVE RELEASES

4.1. RELEASES FROM REPROCESSING

Nuclide releases from reprocessing depend on the tonnages, types, enrichments, storage periods and burn-ups of fuels, which are reprocessed. Nuclear inventories in spent fuel are estimated by computer codes that analyse nuclide concentrations from fission rates and neutron fluxes in reactors. Most codes are derived from US programs for light water reactors, such as ORIGEN or its derivatives.

Nuclide emissions to air from nuclear facilities are transported in radioactive plumes, which deposit particulates and aerosols downwind. This results in contamination of local food chains, including the grass-cow-milk-infant chain. In addition to doses from the ingestion of contaminated local foods, local individuals may also receive radiation doses from immersion in radioactive aerosols, inhalation of radioactive gases and particulate matter, and ground shine from nuclides deposited on land. From nuclides discharged to sea, individuals may receive doses from ingestion of fish, crustaceans and molluscs. The use of contaminated seaweed as animal feed and as fertiliser, the return of nuclides via sea spray and foam are additional marine contamination pathways.

Various computer models have been designed to estimate radiation doses to members of critical groups living near nuclear facilities from nuclide releases. These groups are expected to receive the highest levels of radiation: limits are designed to protect these individuals on the theory that if these people are protected, all other individuals in the population will also be protected. As discussed below, these critical group limits only protect individuals and not populations.

4.2. COLLECTIVE DOSES

4.2.1. Introduction

Radiological impacts of nuclide discharges are conventionally measured in two ways. First, by estimating the average individual dose to members of critical groups near nuclear facilities; second, by estimating doses to whole populations affected by nuclide discharges. The latter are usually termed collective doses. The main advantage of collective dose is that, were only individual dose used, the “dilute and disperse” approach to waste management might be encouraged rather than the “retain and concentrate” approach preferred by some Member States [see DETR, 2000].

Differences of view exist within radiation protection circles over the usefulness of collective dose. On the one hand, international agencies and some national authorities use and recommend the use of collective doses. For example, the European Commission has implemented a Directive (Euratom 96/29) containing detailed procedural requirements on collective dose, as described in ***Annex 6***. On the other hand, despite legal requirements and authoritative recommendations, there remains a reluctance within the nuclear industry and some national regulatory agencies to embrace collective dose. Although rarely discussed in the open literature, unco-operative attitudes towards the use of collective doses remain in some quarters.

4.2.2. Theoretical Justification

The crucial theoretical underpinning for collective dose lies in the adoption by the scientific community of the Linear No-Threshold (LNT) model for radiation’s adverse health effects [ICRP, 1991; NCRP, 1995]. This model states that there is no level of radiation exposure below which there is no effect: risks continue with declining doses until zero dose. Even the smallest possible dose, i.e. a photon passing through a cell nucleus, carries with it a risk of cancer. Although this is an extremely small risk, it is still a finite risk. The LNT relationship is important for collective dose, as most individual doses in a collective dose are extremely small. The LNT model justifies the estimation of these extremely small doses, and justifies their addition to

produce collective doses. More detailed information on the use and calculation of collective doses is contained in ***Annex 6***.

4.2.3. Global Collective Doses

Global collective doses arise from the discharge of certain nuclides with long half-lives, including tritium, carbon-14, chlorine-36, krypton-85 and $^{129}1$, which are globally distributed and act as long-term low-level sources of radiation exposure to the world's population. Recent high discharge levels of technetium-99 have prompted consideration of its likely global distribution [Fairlie and Sumner, 2001]. Global compartmental models estimating global doses from releases of several nuclides have been constructed by the IAEA [1985], and the European Commission [Simmonds *et al*, 1996] and [Titley *et al*, 1995].

4.2.4. Important Radionuclides in Reprocessing Releases

Radiation doses depend strongly on the individual radionuclides to which the public is exposed. Therefore a brief description of the main nuclides discharged from reprocessing facilities is set out below.

4.2.4.1. Carbon-14 (^{14}C)

Carbon-14 is a radioactive isotope of carbon with a half-life of 5,730 years: it emits beta particles of maximum energy 156 keV. The major sources of carbon-14 in irradiated nuclear fuel are neutron activation of nitrogen (in fuel as impurity and/or additive) and oxygen (in fuel as UO_2). carbon-14 is retained in spent fuel until reprocessing when it is released in both gaseous and liquid forms.

Carbon-14 is produced naturally in the upper atmosphere as a result of the capture of cosmic ray neutrons by nitrogen-14. Because carbon-14 behaves in the same way as stable carbon, it is rapidly distributed among environmental compartments – stratosphere, troposphere, biosphere and surface ocean waters. Transfers between atmosphere, biosphere and surface ocean waters take place with time constants of a few years; transfer to deep ocean proceeds more slowly.

Carbon is a major constituent of all life forms. All carbon-14, whether anthropogenic or naturally-occurring enters the natural carbon pool including all biota. Because the half-life of carbon-14 is 5,730 years, doses from carbon-14 introduced into the environment will be delivered to local, regional and global populations for many generations. carbon-14 is the main (>80%) contributor to collective doses from reprocessing discharges, as discussed in ***Chapter 7***. Carbon-14 collective doses are similar whether released to atmosphere or sea.

4.2.4.2. Krypton-85 (^{85}Kr)

Krypton-85 is a strong beta-gamma emitter with a half-life of 10.7 years. It is a fission product retained in reactor fuel until released during reprocessing. Krypton-85 released to atmosphere exposes people to external beta irradiation of the skin, and to uniform whole body gamma irradiation. Although the dose from a single decay of krypton-85 is small, the amounts of krypton-85 discharged are very large – the largest of all nuclides emitted by reprocessing. Accordingly doses from krypton-85 are appreciable. Krypton-85 distributes uniformly throughout the earth's atmosphere within a few years after release, so collective doses from krypton-85 are important.

Krypton-85 is an inert gas and is currently not thought to enter life processes nor be incorporated in biota, unlike iodine-129, carbon-14 and tritium. Krypton-85 dosimetry is based on theoretical models rather than experimental data. The little data which exists refer to acute, non-equilibrium exposures: it is difficult to estimate long-term doses reliably from such information.

4.2.4.3. Iodine-129 (^{129}I)

Iodine-129 is a weak beta emitter with a half-life of 16 million years. It is produced during the fission of uranium with a yield of 1% and is released during reprocessing in large quantities. Its long half-life means it will widely distribute in the environment, become part of the iodine pool, and deliver a thyroid dose to the global population. Iodine is mobile in the environment, and rapidly incorporated in foodstuffs. The highest environmental concentrations of iodine occur in seawater.

Considerable uncertainty surrounds the transfer of iodine-129 to deep oceans and the sedimentation processes that may remove activity from biological chains [UNSCEAR, 1988]. The observed residence time of iodine in the ocean is about 100,000 years [Raisbeck, 1995]

The estimation of radiation doses from all environmental radionuclides is carried out by models of varying complexity. Their results should be validated by comparison with environment measurements.

The lack of monitoring and model validation for iodine-129 releases from La Hague has been criticised by CRII-Rad [1997]. Their report drew attention to iodine-129 measurements one or two orders of magnitude higher than those predicted by the MARINA model. It stated that these under-estimations were probably due to incorrect iodine concentration factors.

CRII-Rad also pointed out that the estimation of doses to individuals did not take into account use of seaweed in industrial applications (e.g. extraction of polysaccharides from *Chondrus crispus* for use in ice cream, desserts etc.), and use of seaweed as an agricultural fertiliser. Iodine in seaweed can be transferred to vegetables with very high transfer factors; for maize the concentration factor is 3. Raised iodine-129 levels in seaweed is not just local to La Hague, but occurs on the French coast from North Brittany to the Pas-de-Calais, and to a lesser extent on the south coast of England and on North Sea coasts.

The release of iodine-129 to atmosphere is an important component of dose to the "terrestrial" (i.e. land) critical group. Predicting iodine-129 concentrations in milk is a difficult and uncertain process: widely different values of iodine-129 dose have been estimated around the Sellafield plant [Fulker *et al*, 1997a].

Problems with iodine-129 dosimetry include:

- Uncertainties concerning the chemical and physical forms of iodine, i.e. the proportions of organic, inorganic and particulates iodine.
- Iodine-129 is difficult to measure at the concentrations encountered in the environment
- Some parameters in iodine models are very uncertain, including the grass to milk parameter [Fulker *et al*, 1997a, 1997b] .

Recently it has become possible to measure iodine-129 using neutron activation analysis, which has a lower limit of detection. The Groupe Radioécologique Nord Cotentin, chaired by Dr. Annie Sugier, Director of Protection at the French National Institut de Protection et de Sûreté Nucléaire (IPSN) has highlighted [GRNC, 1999] the significant difference between calculated and measured quantities of iodine-129 discharged into the environment. However, the Group did not analyse possible reasons for this nor potential impacts of the problem. It has been shown (see ***Annex 25***) that considerable differences exist between estimated iodine-129 inventories in fuels processed and actual iodine-129 releases: up to 50% of the theoretical activity could not be accounted (see ***Chapter 6*** on La Hague).

4.2.4.4. Tritium (^{3}H)

Tritium (^{3}H) is the radioactive isotope of hydrogen. It is a weak beta emitter with a maximum decay energy of 18 MeV, and a half-life of 12.3 years. Tritium is formed naturally through cosmic ray interaction with H in the upper atmosphere. However, anthropogenic tritium emissions considerably exceed natural sources. Tritium commonly occurs as tritiated water, i.e. ^{3}HOH, and as elemental tritium gas, ^{3}HH. Tritium is created in nuclear fuel by the activation of hydrogen (^{1}H) and deuterium (^{2}H), and as a tertiary fission product. Some tritium is released at reactors but the majority is released from reprocessing plants at fuel dissolution stage.

In some respects, tritium is an unusual radionuclide. The high mobility of tritiated water in the biosphere, cycling in the biosphere, multiple pathways to man, ability to bind with cell constituents to form Organically Bound Tritium, and the heterogeneous dose distribution of bound tritium mark it out, potentially, as a hazardous radionuclide. These characteristics are not reflected in tritium's safety limits that are based on its dose per unit intake, which is relatively low. In sum, tritium is a very efficient distributor of radioactivity in the environment and in the human body [Fairlie, 1992].

Ingested tritiated water has a biological half-life of about 10 days. Ingested tritiated foodstuffs (OBT) have much longer half-lives, which are poorly defined and may extend to several years in some tissues.

4.2.4.5. Technetium-99 (^{99}Tc)

Technetium-99 is a radioactive isotope of technetium, which emits beta particles and has a half-life of 214,000 years. It is produced at relatively high yield in the fission of uranium.

Technetium does not occur naturally in the environment. Globally, the dominant sources of technetium-99 are fallout from nuclear weapons testing in the atmosphere, releases from nuclear fuel reprocessing and the use of ^{99m}Tc (which decays into ^{99}Tc) in diagnostic nuclear medicine [Smith *et al*, 1997]. Technetium is

present in the marine environment mainly in the form of the pertechnetate ion (TcO_4^-), which is soluble and may be transported over long distances.

In the human body, the pertechnetate ion behaves in a similar way to the iodide ion, i.e. it concentrates in the thyroid (although unlike iodide it is not incorporated into hormones). Hardly anything is known however, about the possible existence of other chemical forms, and their stability and environmental pathways.

Because technetium-99 is soluble and unbound to sediments, it travels rapidly from its point of release. From Sellafield, the transit time to the North Channel (between Northern Ireland and South West Scotland) is about 3 months, to the Northern North Sea 6 months and the Norwegian Coastal Current around 2.5 years [Leonard *et al*, 1997].

4.3. UNCERTAINTIES IN RISK ASSESSMENT

There are two main ways to assess potential environmental and health impacts associated with reprocessing discharges:

• ***direct measurement*** of environmental contamination, and of health effects (i.e. morbidity) through epidemiological studies;

• ***use of computer models***, on dispersion/concentration of nuclides in the environment, and on the evaluation of doses to critical groups and to populations.

In practice, the two approaches are complementary, and linked: measurements are needed as for input and benchmarks for models, and models are used to establish monitoring priorities in the environment and epidemiological studies.

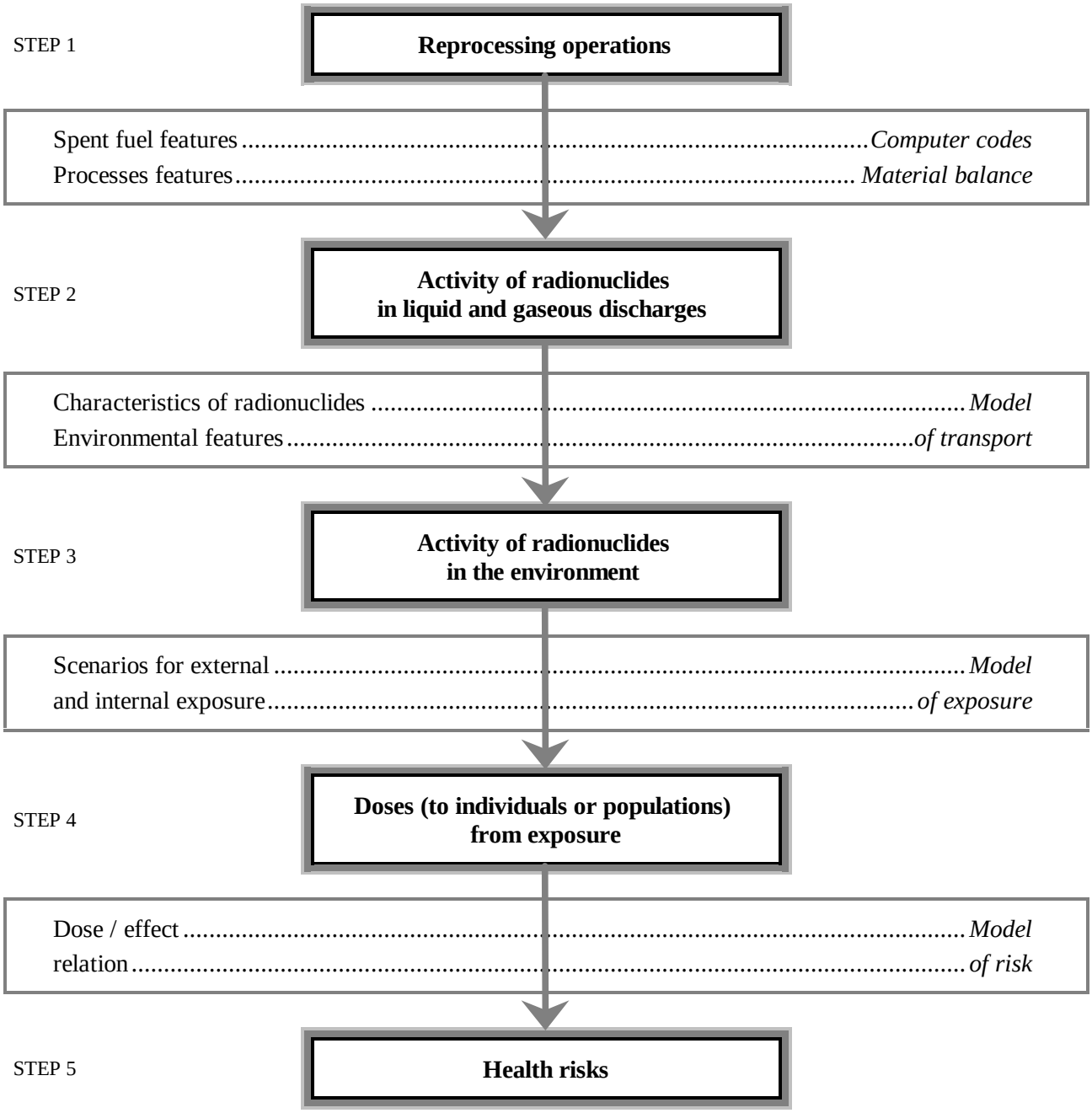
Figure 1 illustrates successive steps taken in an evaluation of environmental and health risks from reprocessing operations based on models, and the areas of associated uncertainties. This is similar to the approach used by GRNC (Groupe Radioécologie Nord-Cotentin) in their evaluation of health risks around the La Hague plant. Each step uses models, sometimes validated by measurement, and each involves many parameters and the use of many assumptions, which result in high levels of uncertainty. After a brief description of the steps is given below, the main uncertainties lying in this evaluation process are discussed in relevant chapters of the report [on some of the uncertainties found in these approaches, see Smith *et al*, 1998; IPSN, 2001].

The starting point is the set of assumptions used in computer models to assess nuclide inventories in spent fuel. Data on spent fuel reprocessed, especially its type, initial enrichment and burnup, are used in computer codes to calculate the nuclide content of spent fuel, hence the input of various nuclides into the reprocessing plant. To assess actual discharges, detailed knowledge (based on theoretical calculations by the plant engineers) of the physical and chemical processes in the plant, leading to the release of nuclides to air and sea is required. These releases are verified through material balance assessments in the plant, which will include stack measurements of discharges.

This results in the nuclide inventories in gaseous and liquid discharges. Then physical data on the nuclides, and their behaviour in relevant environments are used to estimate their concentrations in the environment. The estimates derived from these tranport models have to be validated by measurements in the environment. Local data are used for local and national models, rather than global models. In the case of certain long-lived nuclides, global transport models are also necessary.

Estimates of concentrations in the environment allow for the evaluation of doses to critical groups and to populations through the definition of exposure scenarios. Finally, models of the dose-effect relation, like those defined by the ICRP, are used to estimate the heath risks.

Figure 1 Uncertainty in the Evaluation of Environmental and Health Risks from Reprocessing Operations



5. CASE STUDY SELLAFIELD

5.1. NATIONAL REGULATORY FRAMEWORK

The United Kingdom has developed a large set of national nuclear regulations in the five decades its atomic energy programme has been in operation.[15]

The Food Standards Agency – which has the legal status of a Government department but without a minister – also plays a role in nuclear regulation and radiological protection in the UK.

The first nuclear regulation dates to the passing of the Radioactive Substances Act in 1948. Next came the Atomic Energy Act in 1954, followed by the revised Radioactive Substances Act in 1960. In 1959, a *White Paper* – covering the proposed policy framework – was published on radioactive waste, including discharges. This was followed in 1965 by the Nuclear Installations Act, consolidating earlier legislation, covering the licensing of nuclear sites, including reprocessing plants.

The most relevant recent legislation, or draft legislation in process covering radiological protection includes:

- Radioactive Substances Act 1993: Regulation of Radioactive Discharges;
- Variations to the BNFL Sellafield Radioactive Waste Discharge Authorisations: Decisions of the Secretary of State for the Environment, Transport and the Regions and the Minister of Agriculture, Fisheries and Food;
- UK Strategy for radioactive discharges 2001-2020.

In recent years, the United Kingdom government has increased the opportunity for citizens to be consulted policy review via submissions to official Consultations, including the House of Lords Consultation on Radioactive Waste strategy (1998-99); the Environment Agency Consultation on proposed revision of authorisations for technetium-99 and other radioactive waste discharges from Sellafield (2000); and the DETR Consultation on UK Strategy for Radioactive Discharges, 2001-2020 (2000). In addition there is a five part Consultation on discharges and other aspects of the MOX fabrication plant (SMP) at Sellafield, first by the Environment Agency in 1997-98, then by the DETR[16] in 1999, and 2001.

5.2. OPERATIONS AT SELLAFIELD

Reprocessing has been carried out at Sellafield (originally Windscale) since the early 1950s, when the purpose was to separate plutonium for nuclear weapons. Table 1 sets out annual tonnage throughputs since 1970. Early data concerning reprocessing by the (now shut) B204 reprocessing plant is unavailable. Since 1965, the B205 fuel reprocessing plant at Sellafield has been operating principally for commercial purposes. The B205 plant reprocesses Magnox fuel, i.e. metallic uranium fuel clad in magnesium alloy from Magnox gas-cooled reactors. These reactors are in the process of being phased out by about 2010.

Approximately 26,000 tonnes of spent fuel have been reprocessed by the B205 line at Sellafield up to year ending 2000. Estimates vary as to how long reprocessing will continue at B205 [see discussion in RWMAC, 2000] but an informed estimate would be about 2012 based on current annual throughput rates.

[15] Details of the current radiological protection and nuclear licensing legislation may be found on the relevant departmental web sites:
Department of Trade & Industry: http://www2.dti.gov.uk/energy/nuclearsafety.htm
Department of the Environment, Transport and the Regions: http//www.environment.detr.gov.uk/radioactivity.htm

[16] The environmental functions of the former DETR were transferred to the new Department of Environment, Food and Rural Affairs (DEFRA) in June 2001.

The THORP (THermal Oxide Reprocessing Plant) plant started operations in 1994 to reprocess uranium oxide fuel in stainless steel cladding from Advanced Gas-cooled Reactors (AGR) and Light Water Reactors (LWR). So far about 3,200 tonnes of oxide fuel have been reprocessed at THORP.

No new reprocessing contracts (domestic or overseas) are likely at THORP. Estimates vary as to how long reprocessing could continue at THORP [RWMAC, 2000] under current contracts but an informed estimate would be also about 2012 based on its lifetime throughput rate.

Table 1 Annual Fuel Throughputs at B205 and THORP (financial years April-April)

Year	Magnox B205	Year	Magnox B205	THORP
1971-72	880	**1986-87**	983	
1972-73	674	**1987-88**	804	
1973-74	935	**1988-89**	875	
1974-75	995	**1989-90**	1,129	
1975-76	553	**1990-91**	739	
1976-77	1,130	**1991-92**	819	
1977-78	823	**1992-93**	728	
1978-79	666	**1993-94**	1,664	
1979-80	803	**1994-95**	1,059	65
1980-81	859	**1995-96**	1,590	208
1981-82	923	**1996-97**	601	408
1982-83	893	**1997-98**	520	781
1983-84	860	**1998-99**	465	461
1984-85	781	**1999-00**	500	879
1985-86	705	**2000-01**	366	362
		Total	**~25,000**	**3,164**

Sources: CEGB reports, CORE reports, 1971-2 to 83-84 from CEGB reports, 1984-85 to 92-93 from BNFL Data Book. "BNFL to again shut Sellafield plant to boost reprocessing of Magnox fuel" Nuclear Fuel Vol. 25 No. 16, *Aug. 7, 2000; BNFL Annual Reports.*

5.3. RELEASES FROM SELLAFIELD

Releases from Sellafield are presented below. Emissions to air are presented in Figure 2. Liquid discharges are presented in Figures 3a and 3b: light and heavy nuclides (mainly activation products) in the second one, and others nuclides (mainly fission products) in the first one. The reason for the division into two graphs is merely to present the mass of data points more clearly, not because there is any difference between their treatments at Sellafield. Logarithmic Y-axes are used to encompass the wide ranges of data. It should be noted that logarithmic scales do not show small fluctuations in data points.

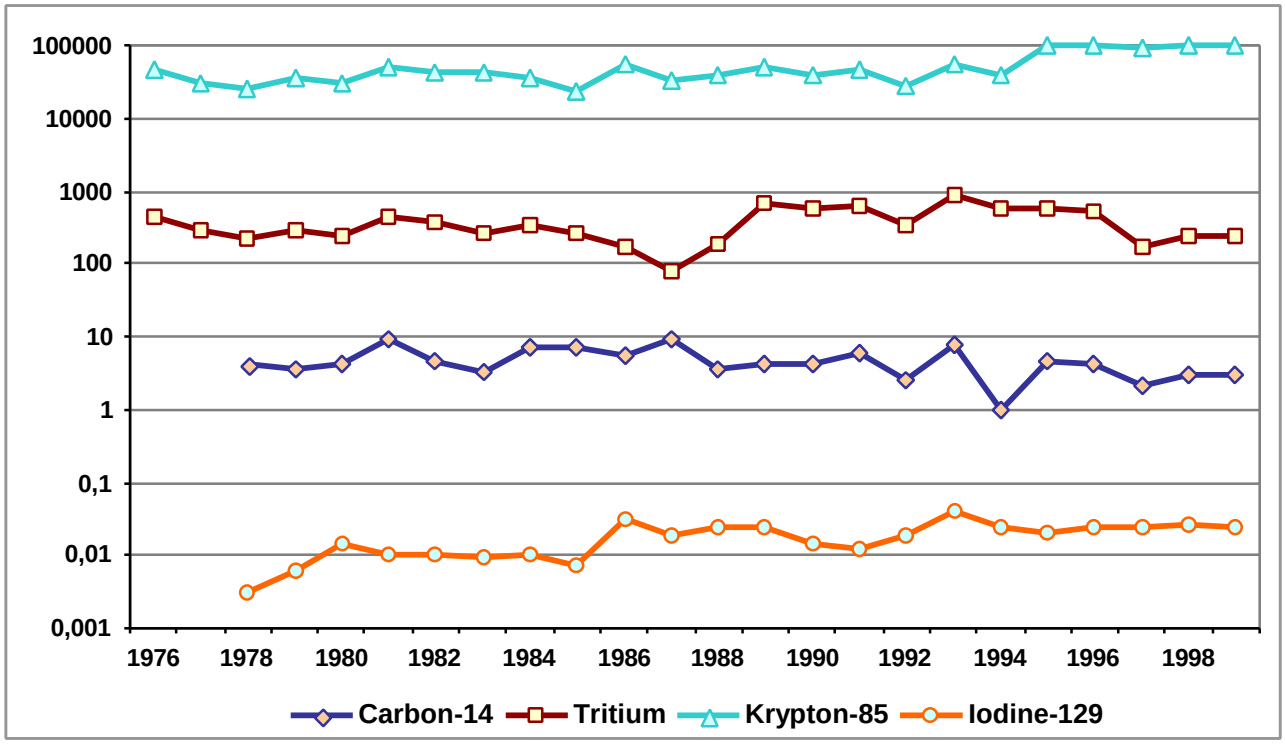
5.3.1. Air Emissions

It may be seen from Figure 2 that radioactive air emissions at Sellafield have not varied to a marked extent since the 1970s, with the possible exception of iodine-129 emissions which have increased 10 fold in this 20 year time period. As stated in ***Chapter 4***, radiation protection concerns exist over iodine-129, which has a 16 million year half-life.

The question of the contribution of carbon-14 releases from the Calder Hall reactors to global Sellafield releases was raised during the research. According to the UK Environment Agency it is insignificant: *"Carbon-14 aerial discharges from Calder Hall nuclear power station are small compared to Magnox*

Reprocessing and THORP and represent only a small percentage (2.3%) of discharges from Sellafield. Carbon-14 is currently discharged to air from the power station without abatement." [17]

Figure 2 Annual Air Emissions from Sellafield Reprocessing Operations, 1976–1999 (TBq)



Source: BNFL Annual Reports on Discharges and Monitoring of the Environment

5.3.2. Liquid Discharges

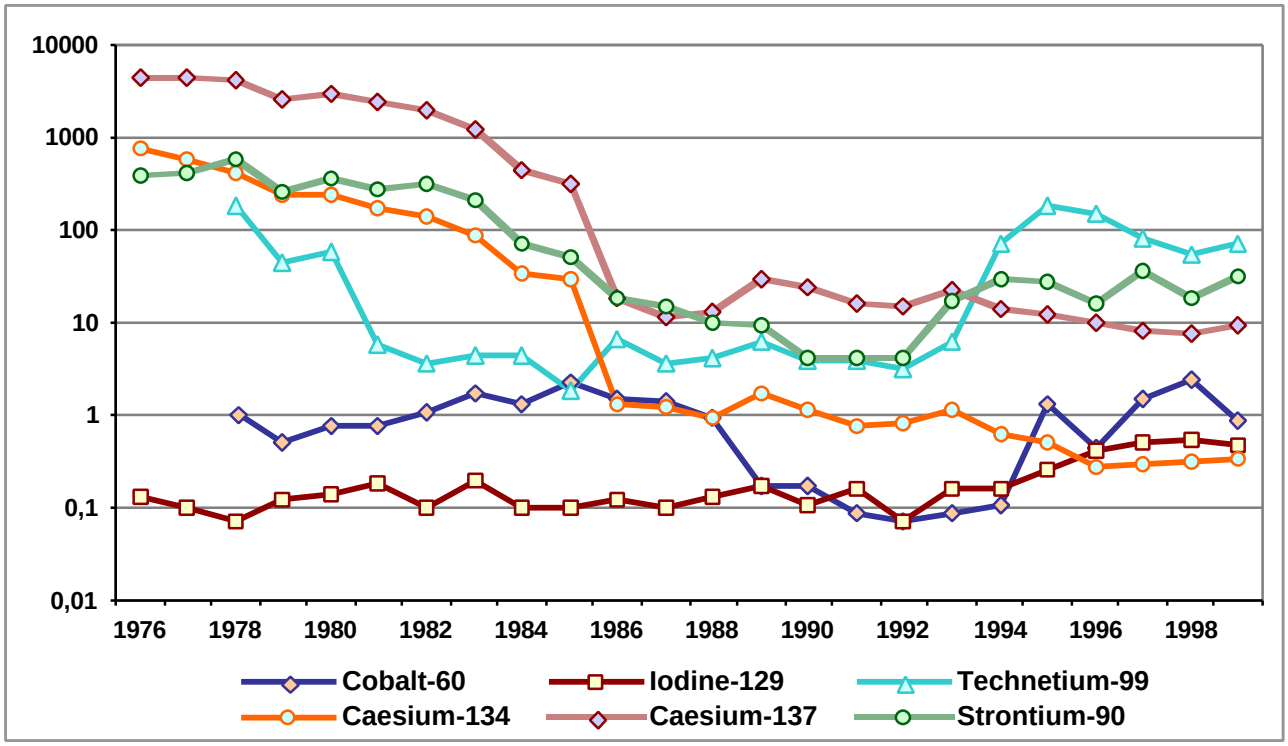
With liquid discharges to sea, the picture is more complex. In the late 1970s, very high levels of fission products and actinides (particularly plutonium isotopes) were contained in pond liquors discharged to sea. These discharges occurred as a consequence of Magnox fuel assemblies being held in ponds for long periods awaiting reprocessing. This resulted in the disintegration of many assemblies and in heavy radioactive contamination of pond liquids. These were subsequently discharged untreated to sea.

In the early 1980s, discharges of carbon-14, strontium-90, caesium-134 and caesium-137 declined markedly as a result of the introduction of a new abatement plant, the Site Ionisation and Exchange Plant (SIXEP) at Sellafield. However, in the mid 1990s smaller increases occurred in carbon-14, cobalt-60, strontium-90, technetium-99 and iodine-129 discharges.

It is understood from the Commission's comments [see European Parliament, undated] that these increases resulted from the reprocessing of older oxide fuels at Sellafield. Technetium-99 increases resulted from the commencement of treatment of 14 years' arisings of Medium Activity Concentrate wastes from Magnox reprocessing which had previously been stored. These wastes were treated by the new Enhanced Actinide Removal Plant (EARP) at Sellafield. Over the same timespan, there has been a notable decline in actinide discharges, partly due to the commencement of EARP operations.

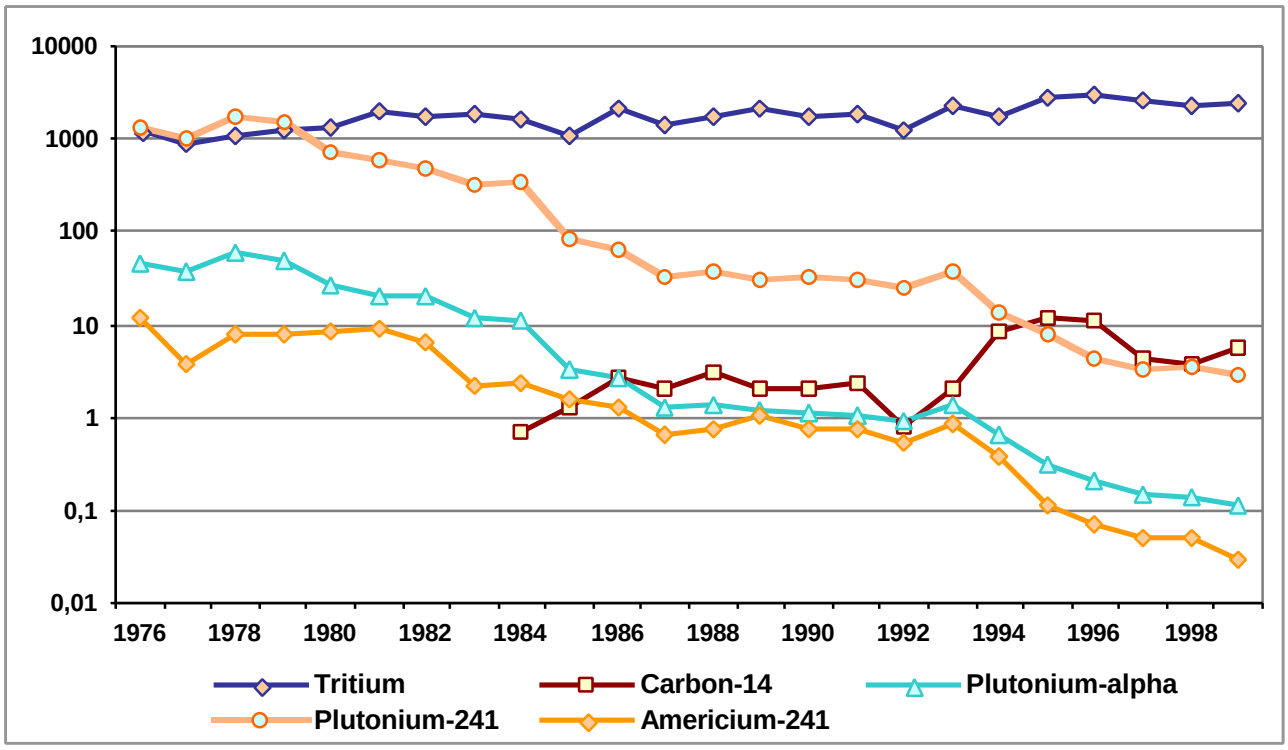
[17] Environment Agency, Explanatory Document for the 2001 Review of Sellafield Releases, Appendix 6, 31 July 2001

Figure 3a Annual Liquid Discharges from Sellafield Reprocessing Operations, 1976–1999 (TBq) Cobalt-60; strontium-90; technetium-99; iodine-129; caesium-134, 137



Source: BNFL Annual Reports on Discharges and Monitoring of the Environment

Figure 3b Annual Liquid Discharges from Sellafield Reprocessing Operations, 1976–1999 (TBq) Tritium; carbon-14; plutonium (alpha, -241), americi um-241



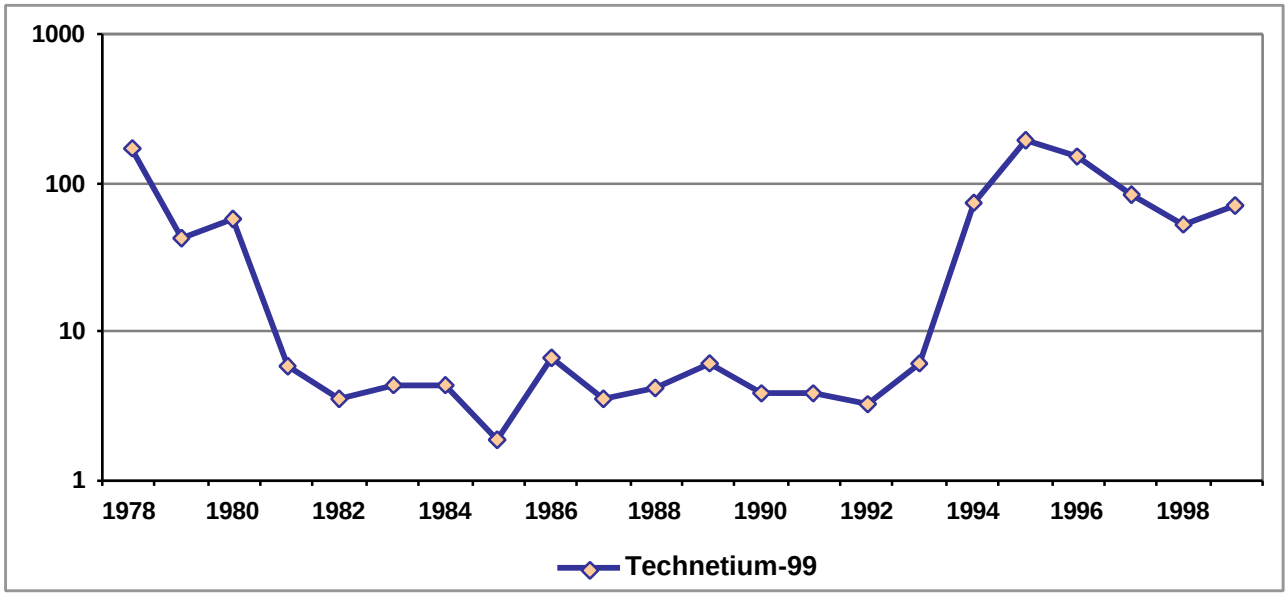
Source: BNFL Annual Reports on Discharges and Monitoring of the Environment

5.3.3. Technetium Discharges

In recent years, concern has been expressed by Member States (including Denmark and Ireland) over technetium discharges from Sellafield. Technetium does not exist naturally in the environment: all concentrations found in the biosphere and hydrosphere are man-made. Technetium-99 is mobile in the environment, and has a half-life of 214,000 years, which means that its distribution will eventually be global. It should be noted that technetium discharges result mainly from Magnox reprocessing: it occurs in light water reactor fuel and thus in current La Hague discharges only in relatively low concentrations.

Figure 4 examines annual technetium discharges from Sellafield in more detail. It will be seen that between 1977 (when measurement of technetium discharges commenced) and 1980, technetium discharges were high due to the direct discharge of Medium Activity Concentrate (MAC) wastes as mentioned above. Between 1981 and 1993, MAC wastes were stored in tanks, then from 1994 they were treated in the new EARP plant for the enhanced removal of actinides and caesium isotopes. This plant however does not remove technetium-99 (and has relatively low removal rates of strontium-90, cobalt-60 and carbon-14 as seen from Figures 3a and b). This lack of removal capability was known in the early 1990s during the planning stages of EARP. However the decision was then taken that the increased cost of additional abatement plant to reduce technetium-99 (and other nuclide) discharges was not worthwhile. The result is seen below in the evolution of discharges, although they have been generally declining since 1995. In November 2000, the UK Environment Agency proposed to permit annual technetium discharges of 90 TBq (million millions or trillion becquerels) from Sellafield. This matter is still the subject of a formal Consultation procedure in the UK.

Figure 4 Annual Technetium-99 in Liquid Discharges from Se llafield, 1978–1999 (TBq)



Source: BNFL Annual Reports on Discharges and Monitoring of the Environment

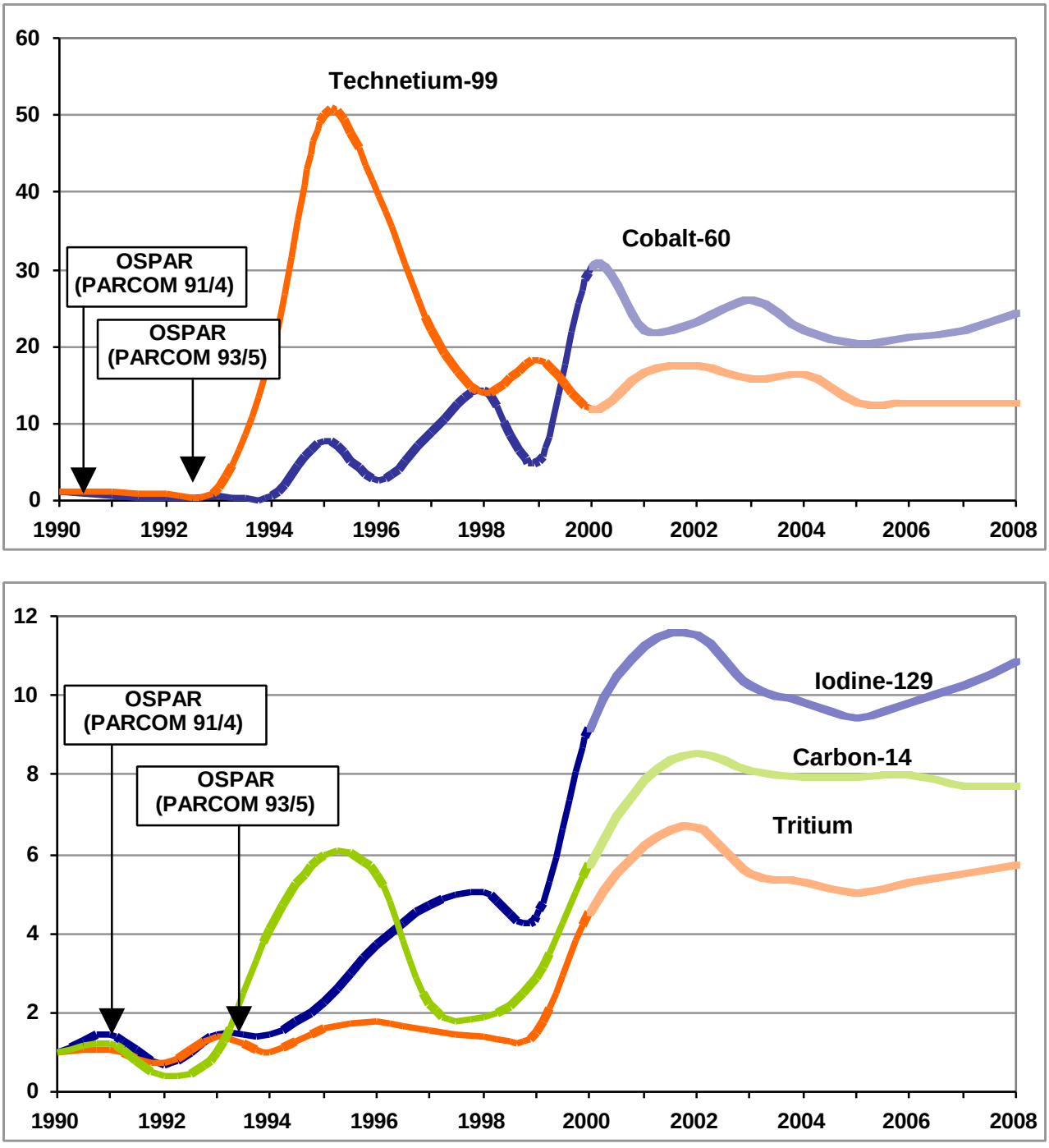
5.3.4. Expected Future Sellafield Discharges

Internal BNFL documents [BNFL, undated] leaked to the UK press and environmental groups in June 2001 suggest that BNFL envisages increases in nuclide releases in the future, as shown in Figures 5 and 6. The document, which contains detailed analyses of current and expected discharges, states as regards liquid discharges: *"Comparison of the total worst case discharge with the current authorised limits (…) shows that discharges of over half of the currently authorised radionuclides are predicted to be at levels approaching or above the limits."*

Figure 5 Past and Projected Liquid Discharges from S ellafield Reprocessing Operations, 1990–2008 (TBq, Index 1 in 1990)

OSPAR (PARCOM 91/4): *"The contracting parties (…) agree (…) to apply the Best Available Technology to minimize and, as appropriate, eliminate any pollution caused by radioactive discharges."*

OSPAR (PARCOM 93/5): *"Contracting parties (…) agree (…) to adopt further measures, including the application of Best Available Techniques for the reduction or elimination of inputs of radioactive substances to the maritime area."*



Source: [BNFL, undated]

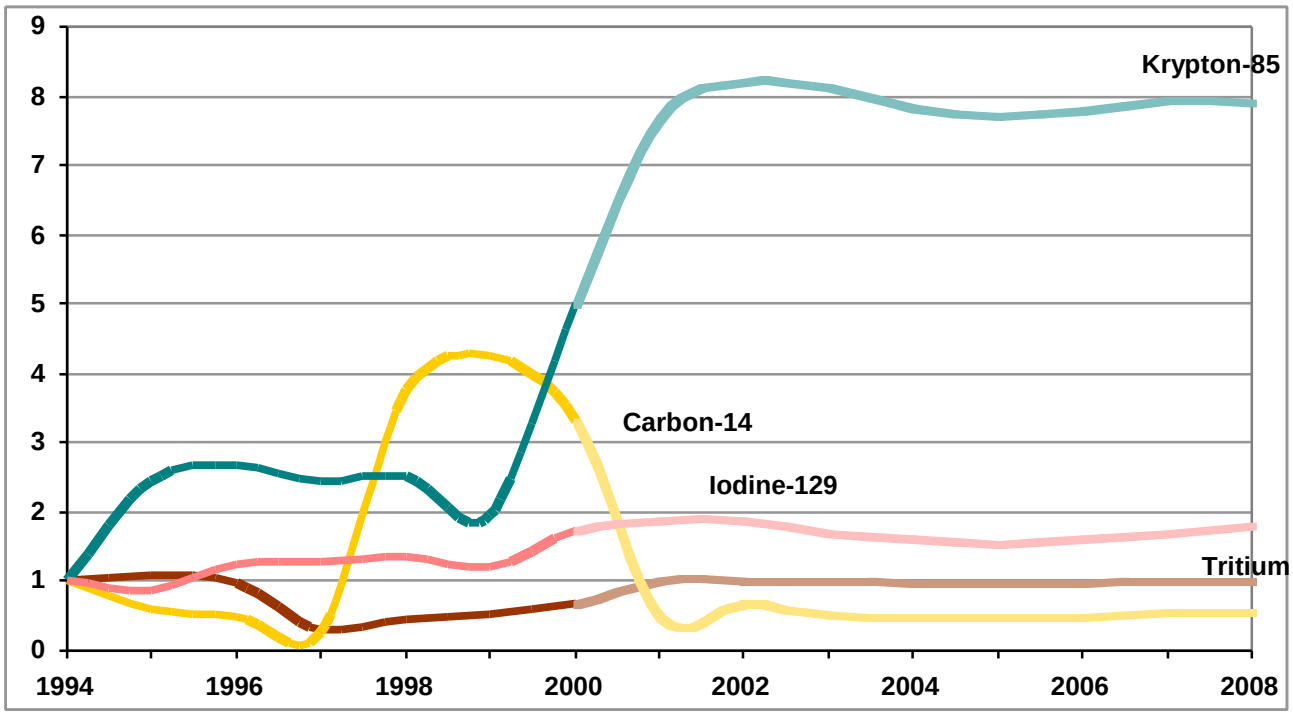
A similar situation was expected with aerial releases from Sellafield: *"A number of predicted worst case discharges are close to or exceed the current annual authorisation limits, which implies a risk that these limits could be breached in future as a consequence of normal activities."*

Increases of Sellafield releases would conflict with the UK Government's obligations set out in various OSPAR resolutions that call for the reduction and eventual elimination of radioactive discharges into the environment.

Figure 6 Past and Projected Gaseous Emissions from Sellafield Reprocessing Operations, 1990–2008 (TBq, Index 1 in 1990)

OSPAR (PARCOM 91/4): *"The contracting parties (…) agree (…) to apply the Best Available Technology to minimize and, as appropriate, eliminate any pollution caused by radioactive discharges."*

OSPAR (PARCOM 93/5): *"Contracting parties (…) agree (…) to adopt further measures, including the application of Best Available Techniques for the reduction or elimination of inputs of radioactive substances to the maritime area."*



Source: [BNFL, undated]

5.4. IMPACT OF SELLAFIELD DISCHARGES

5.4.1. Plutonium and other actinides near Sellafield

When radionuclides are discharged into the sea from Sellafield, some (e.g. fission products caesium-137 and technetium-99) are soluble and diluted in large volumes of seawater. Others (notably plutonium) tend to be concentrated in sediments close to Sellafield, in the Irish Sea and in the Solway Firth. Up to 1995, discharges into the sea of plutonium (alpha) and americium-241 from Sellafield amounted to about 1,600 TBq. Kershaw *et al* [1992] estimate that at least 240 TBq of plutonium-239/240 remains bound to the seabed within a coastal strip approximately 30 km wide, running from Kirkcudbright Bay to the Ribble estuary in the south. The quantity outside this zone amounts to about 40 TBq of plutonium-239/240.

Radionuclide deposition around Sellafield was analysed by Day [1992]. Plutonium deposition plots show two main features: a major deposition peak centred on Sellafield falling sharply with distance, and a minor peak, centred a short distance inland from the Ravenglass Estuary. The peak centred on Sellafield dominates the plutonium deposition map for this part of Cumbria. A slightly raised level of deposition is also apparent along the coastal strip. Peak values of plutonium concentration are about three orders of magnitude higher than the concentrations due to weapons fallout. Day concluded the plutonium deposited within 20 km of Sellafield attributable to aerial emissions was 160-280 GBq, compared with 90 GBq from bomb fallout.

A potentially important pathway for discharged radioactive material to humans involves sea-to-land transfer. Although this mechanism was disregarded before 1980, it has since been established that significant quantities of radionuclides can become airborne in sea spray and be transported inland by the wind [McKay and Pattenden, 1990]. Actinides with an activity of $2.5x10^5$ Bq, equivalent to about 1,000 body burdens, can be transported inland relatively quickly. The average activity due to actinides is 40 $\mu Bq/m^3$ 15-120 m from the sea, and may occasionally exceed the ICRP limit of 1 mBq/m^3 [Branford, 1994].

From these data, the scale of past nuclide discharges from Sellafield may be seen to be large. Consequent concerns have been expressed about resulting nuclide concentrations in the environment. For example, Lambert [1989] and Aarkrog [1997] have estimated that over 40,000 TBq of caesium-137, 113,000 TBq of beta emitters and 1,600 TBq of alpha emitters have been discharged into the Irish Sea since the inception of reprocessing at Sellafield. Baxter [1991] has observed that this means between 250 and 500 kilograms of plutonium from Sellafield is now adsorbed on sediments on the bed of the Irish Sea. Hunt and Smith [1999] have commented that a storm could bring contaminated sediment onshore, leading to increased doses to critical groups in the years following the event. Baverstock [1997] has stated that the migration of undersea deposits of actinides to coastal environments represents a long-term hazard of largely unknown proportions.

Apart from bomb test fallout, past discharges at Sellafield are easily the largest anthropogenic discharges of radioactivity to the oceans. Current discharges from Sellafield and La Hague still rank among the largest anthropogenic releases of radioactivity in the world.

5.4.2. Estimated Doses from Consumption of Irish Sea Fish and Shellfish

The main pathways of radiation exposure for those living near Sellafield are: (1) external radiation from both airborne and deposited radionuclides; (2) internal exposure after inhalation of airborne radionuclides; and (3) ingestion of radionuclides present in foodstuffs.

In the Sellafield area, the critical group is now thought to consist of members of the local fishing community who consume significant quantities of locally caught fish and shellfish. This is contaminated with a number of radionuclides; plutonium and americium are particularly important from the point of view of potential toxicity.

The RIFE-5 report [FSA, 2000], sets out estimated doses to consumers of seafood from the Irish Sea. Those are presented in ***Annex 7***. It will be seen that these estimated doses are relatively low in comparison with the current UK dose constraint of 0.3 mSv/a.

5.4.3. Doses to Critical Groups

A recent review [Jackson *et al*, 2000] of critical groups doses states that, during the 1970s and 1980s, peak doses possibly reached 2.5 to 3.0 mSv per year. Latterly, doses to marine-related critical groups have declined to less than 0.15 to 0.2 mSv per year.

Although there has been a comprehensive programme of environmental monitoring in recent years, there has been limited monitoring, i.e. body scans, of radionuclides in members of the public living near Sellafield. A rather dated study carried out by the UK Ministry of Agriculture (the precursor to the FSA) and the National Radiological Protection Board (NRPB) in 1984-85 found that caesium-137 body contents of 16 adult fish and shellfish consumers near Sellafield were only about one third of predicted values [Hunt *et al*, 1989]. However, measurements of plutonium in autopsy tissues taken at the same time showed higher concentrations in Cumbria [Popplewell *et al*, 1985].

5.4.4. Environmental Concentrations

5.4.4.1. Changes between 1989-1999

The latest RIFE-5 [FSA, 2000] report of the UK Food Standards Agency includes tables that chart concentrations in seafoods from Sellafield between 1989-99. Concentrations of the main radionuclides (carbon-14, technetium-99, caesium-137, plutonium-239 and plutonium-240, americium-241) are measured in winkles, lobsters and cod. These results are presented in ***Annex 8***.

It may be seen from these figures that caesium-137 and transuranic concentrations in seafoods have been generally declining over the past 10 years, reflecting the continuing decline in caesium and alpha emitters

from Sellafield in the same period. The same picture of concentrations in seafood following carbon-14 and technetium-99 discharges is also apparent.

5.4.4.2. Detailed Concentrations in Fish, Shellfish, Sediments and Aquatic Plants

1999 environmental measurements of key nuclides in fish, shellfish, sediments and aquatic plants close to Sellafield are set out in ***Annex 9a***. The same measurements have been made in biota at greater distances to indicate the distribution of radioactive pollution from Sellafield. The data in these tables are obtained from the latest UK RIFE-5 report [FSA, 2000]. In these tables, a number of high concentrations were recorded, some exceeding European Community Food Intervention Levels (CFILs). These high levels give some cause for concern and they have been marked in red for ease of reference.

CFILs were introduced by Council Regulations (Euratom Nos 3954/87, 944/89 and 2218/89) following the Chernobyl accident to restrict the import of contaminated foodstuffs to Europe. These limits in force at present are set out in Table 2.

Table 2 Community Food Intervention Levels (Bq/kg)

	Baby Foods	Dairy Produce	Other Foods
Isotopes of strontium (notably ^{90}Sr)	75	125	750
Isotopes of iodine (notably ^{131}I)	150	500	2,000
Alpha-emitting isotopes of plutonium and transplutonium elements (notably ^{239}Pu, ^{241}Am)	1	20	80
All other nuclides of half-life greater than 10 days (notably ^{134}Cs, ^{137}Cs) (1)	400	1,000	1,250

(1) The following radionuclides are not included in this group: tritium, carbon-14, and potassium-40.

Source: Council Regulations, Euratom Nos 3954/87, 944/89 and 2218/89

These environmental concentrations result in small but measurable radiation doses to local people (see Tables in ***Annex 9a***) discussed below. RIFE-5 report states that the dose to the Sellafield Critical Group from current discharges was 0.21 mSv, c.f. the UK dose constraint of 0.3 mSv. The UK NRPB continues to conclude that radiological hazards from consuming marine foodstuffs at these levels are acceptable.

5.4.5. Technetium Concentrations

5.4.5.1. Technetium-99 Concentrations in Marine Samples

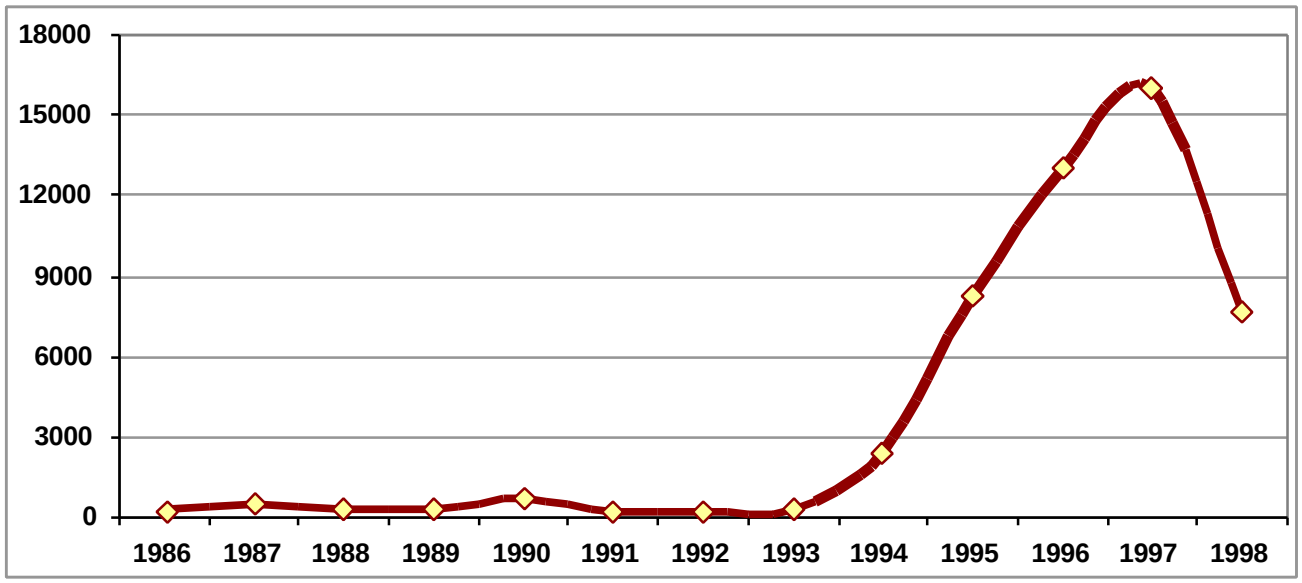
As a result of elevated technetium discharges in the mid 1990s, technetium concentrations in marine biota in the Irish Sea near Sellafield increased. After 1994, technetium-99 concentrations in crustacea – particularly in lobster –, rose reaching a peak of about 16,000 Bq/kg in 1997. This level is 13 times the European Council Food Intervention Level (CFIL) for technetium-type nuclides (1,250 Bq/kg) in post-accident situations. Concentrations in local lobster have subsequently declined, reflecting a reduction in technetium-99 discharges: the highest measurement in 1999 was 4,700 Bq/kg. Figure 7 shows the annual trend of technetium concentrations in lobster.

Some technetium-99 concentrations above CFIL limits have also been found in molluscs (winkles, mussels, limpets and whelks) in the vicinity of Sellafield. In 1995, technetium-99 concentrations in local winkles reached 1,600 Bq/kg [Environment Agency, 2000]. However, generally speaking, technetium concentrations in local molluscs are a factor of 10 lower than in lobsters, and a factor of 1,000 lower in cod. The reasons for these widely divergent concentration factors in marine biota are presently not known.

1996-1997 surveys in Norwegian coastal waters showed technetium-99 concentrations in seawater had increased tenfold compared with 1991 concentrations. This matched the scale of increase observed in the Irish Sea near Sellafield. The travel time from Sellafield to Norway for the initial (1994) pulse of technetium-99 contamination was estimated at about 2.5 years. Recent environmental surveys along the Norwegian coast reportedly indicate a six fold increase in technetium-99 concentrations in seaweed since 1996 – i.e. from 100 to 600 Bq/kg dry weight.

These technetium concentrations result in elevated collective doses to critical groups near Sellafield, and in high collective doses not only to local and UK populations, but also to European and global populations.

Figure 7 Technetium-99 Concentrations in Lobster, in Bq/kg wet weight, 1986 to 1998



Source: Annual MAFF and RIFE Reports

5.4.5.2. Uptake of Technetium-99 by Marine Plants and Animals

In order to estimate the concentrations of technetium-99 in elements of the marine environment for a given level of discharge, computer models are necessary. These models consist essentially of two main parts:

(1) a model to predict the dispersion of technetium-99 in seawater currents and

(2) a model to predict the uptake of technetium-99 from seawater into marine plants and animals. Both modelling stages have associated uncertainties.

A Working Group set up by the Commission of the European Communities used the MARIN1 suite of computer models to estimate the dispersion of radionuclides in northern European waters and their consequent radiological impact. In 1990 they reported that:

"As a tracer radionuclide, ^{99}Tc suffers somewhat from the limited availability of monitoring data. (...) although MARIN1 adequately predicts water concentrations in seas around the British Isles, describing ^{99}Tc dispersion to within factors of a few of measured concentrations, it tends to underestimate at greater distances from the reprocessing plants over the same period. This may be due, in part, to the accuracy of values used in the model for exchange rates in these waters. Any deficiencies in the modelling of ^{99}Tc with regard to transfer coefficients are likely to be compounded by uncertainties in the choice of concentration factor used....in addition to the above uncertainties in the modelling of ^{99}Tc dispersion and uptake, it should be noted that there is also uncertainty about discharges of technetium from Sellafield prior to 1978." [MARINA Project, 1990]

The concentration factor referred to above is the ratio of technetium-99 activity in the tissue of a plant or animal to the activity in seawater. Only limited data are available on technetium-99 concentration factors; there are large and real inter-species differences [Dehut *et al*,1990].

Both aerobic and anaerobic marine bacteria from coastal sediment are capable of concentrating technetium [Vandecasteele *et al*, 1989]. This may result in the transfer of technetium-99 to higher levels in the food chain. Concentration factors are greater than 1,000 for some biota such as macrophytic brown algae, worms and lobsters [Masson *et al*, 1989]. Concentration factors for some seaweeds are particularly high – for example, that for *Fucus vesiculosus* is around 100,000 [Dahlgaard *et al*, 1997].

A recent study of technetium-99 activity in Cumbrian seafood found concentration factors of between 380 and 1,200 in lobster muscle tissue (the part most commonly consumed by man), 7,700 in the hepatopancreas

and 65,000 in the green gland. In *Nephrops* (the Norwegian lobster) the concentration factors are 1,700 for claws and 970 for abdomen muscle. The tail muscle (the part of *Nephrops* most commonly consumed by man) had a higher activity than the average level in lobster, although the authors of the study do not actually report the activity.

Several studies have estimated concentration factors using laboratory experiments, but concentration factors in the marine environment have been found to be one to two orders of magnitude higher than in laboratory experiments [Masson *et al*, 1989]. For example, Busby *et al* [1997] reported concentration factors in winkles and mussels *"much greater"* than any reported from laboratory investigations (>100X in some cases). McCartney & Rajendran [1997] in a study of technetium-99 activities in seaweeds, muscles and winkles confirmed that the uptake (of technetium-99) by marine organisms in the field *"far"* exceeded that expected from laboratory studies. They concluded that, given the radiological importance of this nuclide, the provision of more accurate information on its environmental behaviour was required.

It should be noted that ingestion of seafood containing technetium-99 may not be the only pathway by which humans incur radiation doses. In some areas, seaweed is used as agricultural fertiliser. A report published by Atomic Energy Authority Environment and Energy at the Harwell Laboratory [Nicholson *et al*, 1992] estimates that, if seaweed were used in this way, individual doses from this pathway alone could be around 260 µSv per year (assuming a discharge rate of 200 TBq per year).

Our present understanding of the behaviour of technetium-99 was summarised by Zeevaert *et al* [1989]. *"Despite the substantial amount of quantitative information about the transfer of technetium in the biosphere that has recently become available, large uncertainties in this field persist."* Twenty years ago in a key study, Ng [1982] warned that long-term extrapolations based on short-term experiments were risky: this warning remains relevant. This remains the case in 2001.

A recent study carried out on behalf of the German Office for Radioprotection [Beninschke, 2000], using German statutory dose assessment assumptions, calculated the dose impact of seaweed use as fertiliser. Annual induced effective doses from consumption of contaminated foodstuffs were 5.88 mSv for adults and 5.82 mSv for children. That is more than 5 times the annual limit imposed by the European legislation (1 mSv per year) and about 20 times the annual dose constraint used in UK and Germany (0.3 mSv per year). Most of the calculated dose was received via the seaweed fertiliser/animal feed/meat consumption pathway. The authors used the consumption habits, transfer factors and other assumptions prescribed by German legislation. European legislation does not prescribe specific assumptions in dose assessment models. The European Commission has stated that *"the guidance currently being produced on realistic dose assessments will comment on this issue."* [18]

This raises the question of the differences between the values used for consumption habits and life patterns in models used by national authorities to calculate doses to individuals near reprocessing plants and other nuclear facilities. The European Commission has stated that it is *"working to prepare guidelines on the harmonisation of realistic assessment of doses. Article 45 of the new Basic Safety Standards Directive indeed states that Member States competent Authorities shall ensure that dose estimates from practices subject to prior authorisation shall be made as realistic as possible for the population as a whole and for reference groups."*[19] However it is noted that Article 45 concerns population (i.e. collective) doses rather than individual doses.

The German Federal Office for Radiation Protection recently stated: *"On the question what is 'realistic', there is no consensus visible on the short term on the EU level. A corresponding examination in national and international framework is considered urgently necessary."* [20]

5.4.6. Conclusions on Concentrations and Doses

National radiological authorities state that radionuclide concentrations in local contaminated materials continue to result in doses to critical groups that fall within agreed safety limits. These conclusions are reached after dose estimates have been arrived at through the use of computer models using many assumptions and estimated parameters. Although these dose estimates are best estimates arrived at using the

[18] Stephen Kaiser, Commission of the European Communities, e-mail to Mycle Schneider dated 12 June 2001.
[19] ibidem
[20] See: http://www.bfs.de

best endeavours of regulatory teams in both countries, nevertheless large uncertainties remain. For example, the NRPB [Smith *et al* , 1998] has concluded that uncertainties in dose estimates via the food chain may be very large: differences between 5th and 95th percentile values, for example, often exceeded three orders of magnitude.

These uncertainties are discussed further in ***Annex 10***.

In addition, the effects of historical discharges are not considered when comparing radiation doses with the dose constraint. This is an important factor as these doses from past discharges at Sellafield are considerably greater (probably by a factor of 3) than doses from current discharges.

Also as discussed above, current concentrations of radionuclides in the marine environment near Sellafield could already lead to doses that exceed the UK and German constraint by a factor of 20 and the current European limit by a factor of 5 for a *"reference person"* [Beninschke, 2000], with food consumption patterns as defined in the German legislation. The conclusion would appear to be that the Sellafield facility would not be suitable to receive a license to operate in Germany at current levels of discharge.

In addition, German dose limits for organs (also used in the US but not in the rest of the EU) would also be exceeded by the ingestion of relatively small quantities of seafood from Sellafield. For example:

- consumption of 3.41 kg of winkles from St. Bees in the vicinity of Sellafield is sufficient to reach the adult limit for bone surface [Beninschke, 2000, see Table 5.1-11];
- consumption of 11.6 kg of food grown on soil fertilised with contaminated seaweed from the Irish Sea is enough to reach the dose limit for the lower colon of a small child [id., Table 5.1-16];
- consumption of 4.44 kg of meat of beef fed with seaweed from the Irish sea is enough to reach the dose limit for the lower colon of an adult [id., Table 5.1-19]; the consumption of 0.6 kg is enough to reach the limit for small children [id., Table 5.1-20].

5.5. THE HAZARD POSED BY LIQUID HIGH LEVEL WASTE AT SELLAFIELD

Reprocessing at Sellafield has generated large inventories of radioactive waste, in various physical and chemical forms.[21] A substantial part of this waste is in readily-mobilisable forms, including liquids and sludges. The potential exists for unplanned releases of radioactive material from the Sellafield waste inventories. This potential is especially great where the waste is held in a readily-mobilisable form.

The largest hazard of this kind is posed by the storage of high-level radioactive waste (HLW) as a liquid.[22] The loss of cooling to a High Active Liquor feed vessel was also considered as a reference accident by the UK authorities in the case of Sellafield in their General Data submission to the European Commission. Reprocessing at the B205 and THORP facilities produces comparatively dilute liquid HLW, and this liquid is transferred through shielded overhead pipelines to the B215 facility. There, the concentration of the liquid HLW is increased in evaporators, and the concentrated liquid is stored in 21 above-ground steel tanks. The liquid HLW is self-heating due to the very high levels of radioactive decay. This method of storing HLW has been used since reprocessing began at Sellafield in the 1950s, and was adopted because it is comparatively inexpensive.

The concentrated liquid HLW in the tanks is hot and acidic, and requires constant cooling, agitation and supervision. If cooling were to be interrupted, the liquid could begin boiling after about half a day and evaporate completely over a subsequent period of about three days, leaving a solid residue that would oxidise and melt.[23] Volatile radionuclides – such as caesium-137 – would be evaporated from the solid residue and could pass through the ventilation system to the atmosphere.

[21] These and other radioactive waste inventories in the UK are catalogued periodically by the UK government. [See, for example, DETR, 1999]

[22] Liquid HLW poses the largest hazard of an unplanned release at Sellafield because of: (i) its large inventory of long-lived radioactivity; and (ii) its readily-mobilisable form.

[23] The timing of tank boiling and dry-out would vary with the characteristics of the liquid HLW. The times mentioned here are BNFL-calculated numbers for liquid HLW from PWR fuel aged 5 years after discharge from a reactor. [See Thompson, 1998, Appendix C]

Caesium-137 is an important indicator of the hazard potential of the liquid HLW at Sellafield. This fission product is volatile, and is therefore released to the environment in comparatively large quantities during accidents at nuclear facilities. Caesium-137 has a half-life of 30 years, adheres to surfaces when deposited from an atmospheric plume, and emits intense gamma radiation. The 1986 Chernobyl reactor accident released about 85,000 TBq (27 kg) of caesium-137 to the atmosphere, accounting for most of the offsite radiation exposure from the accident. For comparison, the 1,300 cubic metres of liquid HLW, currently stored at Sellafield [NII, 2000c], contain about 7 million TBq (2,100 kg) of caesium-137 [Thompson, 1998, Appendix D].

Analyses have shown that influences such as human error, equipment failure, natural forces (e.g. earthquake) or acts of malice could initiate a sequence of events that releases a substantial fraction of the radioactive material in the liquid HLW tanks to the environment, either as an atmospheric plume or as a liquid release to the Irish Sea. Events that could breach a tank and its surrounding concrete cell, leading directly to a liquid or atmospheric release, include an explosion, aircraft crash, earthquake or act of sabotage. A larger atmospheric release could arise indirectly from such events. The initial event – an explosion, for example – could disable tank cooling systems and radioactively contaminate the vicinity of the affected tanks to a level that would preclude the restoration of cooling. Then, the affected tanks would dry out, and volatile radionuclides would evaporate from the solid residue. This release could contaminate the vicinity of the tanks to a higher level, precluding the ongoing provision of cooling to unaffected tanks. Thus, the initial event could ultimately lead to an atmospheric release from every tank that contains liquid [Thompson, 1998].

In 1957, an atmospheric release occurred from a liquid HLW tank at a military reprocessing plant near Kyshtym, USSR, when the tank dried out and exploded. Reprocessing plants are prone to chemical explosions, as is shown by incidents in Japan, the United States and Russia/USSR. A particular concern at Sellafield is the potential for an explosion in one of the evaporators at the B215 facility, due to inadvertent forwarding of organic chemicals from the B205 or THORP reprocessing plants. An explosion in an evaporator could ultimately lead to an atmospheric release from every liquid HLW tank, as explained above [Thompson, 1998, Appendix G].

The long-term consequences of a release from the Sellafield HLW tanks could be much greater than the consequences of the Chernobyl accident, due to the large amounts of caesium-137 and other radioisotopes in the Sellafield tanks. According to the US Department of Energy (DOE), the Chernobyl release caused a 50–year Northern Hemisphere population dose commitment of 1.2 million person-Sv, primarily from the 90,000 TBq of caesium-137 in the release[24] [DOE, 1987]. An atmospheric release from the Sellafield HLW tanks could include a substantial fraction of their inventory. Assuming a 50 percent release (3.5 million TBq of caesium-137), extrapolation of the DOE's Chernobyl estimate would yield a 50-year Northern Hemisphere population dose commitment of 47 million person Sv from a Sellafield release. This extrapolation should not be regarded as more than a crude estimate of the consequences of a possible Sellafield release, because of the different characteristics of the Chernobyl accident and the postulated Sellafield release, but the result illustrates the potential order of magnitude of the consequences. In 1994, the COSYMA computer model assessed the consequences of an atmospheric release from the Sellafield HLW tanks, to range up to tens of millions of person-Sv [Taylor, 1994].

In 1976, about 600 cubic metres of liquid HLW was stored at Sellafield, and it was predicted that about 6,000 cubic metres would be stored in 2000 [Flowers *et al*, 1976, page 64]. The present volume – about 1,300 cubic metres – is lower because the scale of reprocessing at Sellafield has been lower than predicted, and because vitrification of liquid HLW has been proceeding since 1991. The liquid HLW is transferred from the B215 tanks to an adjacent vitrification plant, where it is incorporated into glass that is cast into steel containers. The containers are stored in a vault where they are cooled by the natural circulation of air. The UK Nuclear Installations Inspectorate (NII) has described the cooling arrangement in this vault as follows: *"This cooling does not depend on the continued availability of installed services such as electricity and water, and is sometimes referred to as passively safe. This may be compared with the situation in B215 where active systems, requiring operator control, are needed to keep the HAL [liquid HLW] in a safe state."* [NII, 2000c, page 4] Production rates at the vitrification plant have been insufficient to eliminate the backlog of liquid HLW stored in the B215 tanks. Thus, BNFL has predicted that the volume of liquid HLW will rise by about 10 percent during the period 2000-2004, after which the volume will begin to fall.

[24] [NEA, 1995] gives a figure of 85,000 TBq released of a total of 280,000 TBq in the core.

BNFL and the NII have been slow to investigate or take action about the hazard posed by the liquid HLW tanks. This hazard was debated during the Windscale Inquiry of 1977, but no action was taken. Public concern about the hazard arose during the 1990s, initially in the context of the commissioning of THORP, and has continued at a high level. In response to ongoing public concern the NII eventually required BNFL to perform safety analyses and to undertake repairs and modifications to the B215 facility. However, neither BNFL nor NII has ever published any of its safety analyses for B215.

In January 2001, the NII issued BNFL with a Specification (a legal order), which limits the volume of liquid HLW to 1,575 cubic meters, lowers this limit by 35 cubic meters per year until 2012, and requires a subsequent reduction to 200 cubic meters in 2015; thereafter, BNFL would be permitted to store 200 cubic meters of liquid HLW as a buffer stock [NII, 2000c]. This Specification is designed to accommodate BNFL's business plan, and to minimise the cost and inconvenience to BNFL of reducing the stock of liquid HLW.

Although the liquid HLW tanks at B215 pose the largest hazard of an unplanned release at Sellafield, this hazard is not unique. Other facilities at Sellafield contain significant amounts of radioactive material, often in a readily-mobilisable form. Transport of radioactive material to and from Sellafield also creates a potential for unplanned releases. Analytic techniques – known as probabilistic risk assessment (PRA) – have been developed, whereby the probability and consequences of unplanned releases can be investigated.[25] PRA findings, properly applied, can provide a basis for public debate about the hazard posed by a nuclear facility, and can guide regulatory action to address that hazard.[26] No PRA study has ever been published for any facility at Sellafield or any transport operation associated with Sellafield, although BNFL officials have conceded that the preparation and publication of PRA studies would be required if the Sellafield site were licensed in the United States. There is evidence that the quality of BNFL's unpublished safety analyses does not meet contemporary PRA standards [Thompson, 1998; 2000b].

5.6. HEALTH EFFECTS AT SELLAFIELD

The attribution of possible health effects to contamination from radioactive discharges at Sellafield has proved difficult and contentious. Most controversy centres on the issue of childhood leukaemia and cancer.

5.6.1. Childhood Leukemia at Seascale

In 1983, the UK Yorkshire Television company produced a film which reported a higher incidence of childhood leukaemia in the village of Seascale, near Sellafield, than was expected from national incidence rates. The Prime Minister at that time, Margaret Thatcher, set up a Committee of Enquiry chaired by Sir Douglas Black. The Black Committee asked the National Radiological Protection Board (NRPB) to estimate the probable radiation doses to children in Seascale from the discharges. These calculations showed that, using conventional dosimetry and risk factors, the radiation doses likely to have been received from the discharges were too low (by a factor of >200) to result in the observed incidence of leukaemia [Stather *et al*, 1984 and Addendum]. Subsequently, a permanent Committee was set up to study aspects of radiation in the environment (Committee On Medical Aspects of Radiation in the Environment – COMARE).

More than fifteen years of research has established that the excess incidence of childhood leukaemia around Sellafield is statistically significant, i.e. highly unlikely to be a chance finding. Craft *et al* [1993] examined the incidence of cancer in young people under 25 years of age in 1,272 census wards in the north of England in the years 1968-85 and found that, of the six electoral wards with the most extreme excesses of lymphoblastic leukaemia in young people under 25, two were close to Sellafield – Seascale 3 km to the south (4 cases, expected 0.3) and North Egremont 7 km to the north (4 cases, expected 0.6).

A further study of the period 1963-90 by Draper *et al* [1993] showed that the incidence of malignant disease continued to be higher than expected in Seascale. COMARE concluded that the raised incidence of leukaemia and non-Hodgkins lymphoma in the young people of Seascale, and its persistence over several decades, were *"probably unique"* in the UK [COMARE, 1994]. As noted above, doses from environmental radioactivity were not thought high enough to explain the raised incidence of leukaemia.

[25] The state of the art for nuclear reactor PRAs is illustrated by [NRC, 1990].
[26] For a review of the strengths and limitations of PRA, see [Hirsch *et al*, 1989].

5.6.2. Paternal Pre-Conception Irradiation

In 1990, an alternative explanation was offered by Martin Gardner and colleagues [Gardner, 1990] who showed an association between pre-conception radiation dose to a father and leukaemia risk in his children. Gardner estimated that a dose of 100 mSv or more to a father was associated with a six-fold increase of leukaemia risk in children born subsequently. The implication was that ionising radiation caused a mutation in the father's sperm, which can be expressed as leukaemia in his children.

There remain several problems with this hypothesis [see Baverstock, 1993]. It is not consistent with the observed incidence of leukaemia in the survivors of Hiroshima and Nagasaki, nor is it supported by other studies of childhood leukaemia in the children of nuclear workers. More important, it would imply a rate of production of a specific mutation that was many times greater than the sum of all dominant mutation rates known to occur in humans [Doll *et al*, 1990]. The plausibility or otherwise of the Gardner hypothesis formed the central theme of two cases heard in the High Court of Justice, London, over the period October 1992 to June 1993. The plaintiffs in these cases claimed that the cause of a fatal leukaemia and a non-fatal non-Hodgkin's lymphoma was paternal preconception irradiation (PPI) at Sellafield.

While the court cases were in progress, a study by Kinlen [1993] demonstrated that, contrary to earlier observations, the leukaemia excess included cases who lived (but had not been born) in Seascale. According to Kinlen, of the six cases born in Seascale five had high Parental Preconception Irradiation (PPI >90 mSv). Of five cases born elsewhere, only one was associated with high PPI. Kinlen concluded that the Gardner hypothesis could not account for all the cases in the Seascale cluster. Looking at the problem in another way, if the Seascale excess *were* entirely due to PPI, many more cases should have occurred in West Cumbria *outside* Seascale. As noted above, there is a significant cluster of leukaemia cases in Egremont North; but none of the fathers of these four cases had a recorded dose of PPI [Wakeford and Tawn, 1994]. These findings, together with the problems mentioned above, led the judge to find (in October 1993) in favour of the defendants (BNFL). However, the cause (or causes) of the increased incidence of leukaemia at Seascale remain(s) unclear.

5.6.3. Population Mixing

Kinlen *et al* [1991] have put forward a hypothesis that population mixing results in the spread of viral infections and that childhood leukaemia is a rare consequence of such an infection. This hypothesis appears to be supported by data on the incidence of leukaemia in England, Wales, and Scotland. However, Draper *et al* [1993] have pointed out that the high incidence in Seascale has occurred over an extended period, and was unlikely to be explained by Kinlen's hypothesis, i.e. because population mixing stopped many decades ago. They also pointed out that the risk of childhood acute lymphoblastic leukaemia is doubled in isolated towns and villages, but the excess in Seascale is too large to be accounted for in these ways.

The possibility remains that ionising radiation is at least one of a number of causative factors. COMARE has stated:

"The cause of the excess rate of cancer in the 0-24 year old age range in the village of Seascale is currently unknown. There are a number of possible causes, which may have led to this excess. There is insufficient evidence to point to any one particular explanation and a combination of factors may be involved. As exposure to radiation is one of these factors, the possibility cannot be excluded that unidentified pathways or mechanisms involving environmental radiation are implicated." [Bridges,1993]

In conclusion, the cause or causes of the observed increases in childhood leukaemia near reprocessing facilities are not known, nor is it known whether a combination of factors is involved. Many observers admit radiation is likely to be involved to some degree, but in the absence of working hypotheses, the question remains open. Further consideration of possible explanations is contained in ***Annex 11***.

5.6.4. Other Possible Health Effects at Sellafield

Investigation of possible health effects due to Sellafield discharges has been dominated by the childhood leukaemia issue outlined above. However, some other areas of concern have also arisen.

Stiller [1993] has reported an increased incidence of retinoblastoma in children born to mothers who have lived in Seascale. In 1999, Parker *et al* [1999] reported a statistically significant increasing trend of stillbirth risk with PPI dose among the offspring of workers at the Sellafield nuclear reprocessing plant over the

period 1950-89. However Little [1999] has countered that these findings should be interpreted with caution as they are inconsistent with observations in the Japanese Atomic Bomb survivors. This matter is discussed further in ***Annex 10***.

5.6.5. Conclusions on Health Effects

A statistically significant excess of childhood cancer continues in the area around Sellafield, notably in the village of Seascale. COMARE has examined current leading hypotheses and pathways by which the observed excess could have come about and have been unable to find a convincing explanation. Nevertheless COMARE has recommended support for further research on a number of radiobiological aspects. This indicates that radiation as a possible cause of the cancers has *not* been discounted by COMARE. The authors have verified this in discussion with COMARE members in the UK. The assertion of the European Commission to the contrary among its replies [see European Parliament, undated] to the Committee on Petitions is incorrect.

6. CASE STUDY LA HAGUE

6.1. NATIONAL REGULATORY FRAMEWORK

Hierarchically, the French regulatory framework governing the discharges of radioactive effluents in the nuclear sector can be divided into two levels :

- *The general technical regulation*

The monitoring of effluents discharged by Basic Nuclear facilities (Installations Nucléaires de Base or INB) is governed by the general technical regulations taken at ministerial level in application of the Decree n° 63-1228 of 11 december 1963 concerning nuclear facilities and the Decree 95-540 of 4 may 1995 concerning the discharges of liquid and gaseous effluents and water use of basic nuclear facilities.

- *Fundamental safety standards*

These are mainly recommendations drawn up by the Safety authority (Direction de la sûreté des installations nucléaire, DSIN also called Autorité de sûreté nucléaire, ASN) or codes established by the French nuclear industry. The DSIN's recommendations are in no way legally binding regulations. The nuclear industry is not compelled to abide by them if it proves that alternative means were implemented to achieve the targets.

6.1.1. Authorisations of discharges

French regulation's official acknowledgement of radioactive discharges from nuclear facilities dates back to the early 1960s. At the time, measures were adopted to regulate discharges in application of general laws such as the law of 2 August 1961 on atmospheric pollution and odours.[27]

As far as La Hague's reprocessing activities are concerned, the first document to refer to radioactive effluents, is the Decree of 17 January 1974, of which Section E, Al. 3, explains that *"liquid and gaseous effluents are released in the ambient environment"* in compliance with the regulation in force. The CEA (Commissariat à l'énergie atomique) had in fact applied for an authorisation to modify its treatment facilities, involving the presentation of the whole activities including discharges. The CEA's application for a license to discharge, dated 19 May 1972, introduced annual limits for effluents that were based on surveys that were neither referred to nor included in the document, and which were to become the basis for future authorisations of discharges.

It is only in 1980, 14 years after the facilities had started operating, that regulations specifying general annual maximum limits were issued to restrict COGEMA's radioactive discharges.

In fact, the departmental order of 22 October 1980 authorising COGEMA to release liquid and gaseous radioactive effluents fixed the annual limits for discharges. The limits were then confirmed by the prefectoral orders of 27 February 1984 and 28 March 1984 respectively for gaseous effluents, with:

> *"480,000 TBq for gases other than tritium;*
> *2,200 TBq for tritium;*
> *110 GBq for halogenes;*
> *74 GBq for aerosols."* (Article 1)[28]

and liquid effluents,

> *"37 000 TBq for tritium;*
> *1700 TBq for radio-elements other than tritium;*

[27] "Loi n° 61-842 du 2 août 1961 relative à la lutte contre les pollutions atmosphériques et les odeurs."

[28] "Autorisation de rejets d'effluents radioactifs gazeux par les usines dénommées UP 2-800 et UP 3-A et par la station de traitement des effluents liquides et des déchets solides, dénommes STE 3 sur le site nucléaire de La Hague (Manche), 27 février 1984."

220 TBq for the totality of strontium-90 and caesium-137;
1.7 TBq for alpha radioelements." (Article 1)[29]

In addition to the release of radioactive effluents, rainwater discharges from La Hague were also subjected in the 1980s to an authorisation procedure.

COGEMA was for instance authorised in the ministerial orders of 22 November 1988 to discharge rainwater into Saint-Hélène and Moulinets streams, provided that radioactivity tests are undertaken on regular basis[30].

There are three main disadvantages in the French authorisation system:

- firstly, it regulates annual limitations of discharges and not concentrations. The amount of effluents released into the sea may vary considerably from day to day, reaching sometimes significant peaks of discharges;

- secondly, the classification of the effluents given in the authorisations is far from being detailed (for example, they lack limits for each radionuclide) and the way they were categorised is questionable as far as some radionuclides are concerned.

- thirdly, significant levels of discharges are granted without public access to relevant underlying data that would allow for the justification of these figures.

6.1.2. Licensing Procedures

There are two different legal procedures COGEMA has to go through today, prior to any modification on its discharges into the environment:

• Authorisation procedure

Applications for authorisations of discharges are addressed to the Ministers in charge of Industry and the Environment. It is also submitted for opinion to the Ministers in charge of Health and Civil Security.

They include general information on plans, programs, description of the concerned activities and their predictable impact on the environment, the compensatory measures proposed and the monitoring operations and further information that may be required by the concerned ministers.

The applications are then transmitted to the Prefect who orders a public inquiry and consults with the concerned municipal councils and regional bodies.

The results of the public inquiry and the different meetings are handed over to the Ministers of Industry and the Environment who take the decision to authorise the discharges.

The Ministers' decision determines:

- the limits of discharges authorised for COGEMA,
- the operations of analysis, monitoring and control of these activities,
- the conditions in which the exploiting company gives account to the Ministers in charge of Health and the Environment and to the Prefect, of the water monitoring and the impact of effluents on the environment, and
- modes of information of the public

• Notification procedure

Similarly, notifications are submitted to the Ministers in charge of Industry and the Environment.

In the case of discharges, they indicate the quantities of effluents and their composition as well as the conditions in which such activities are to be carried out. A document must provide the necessary information on the impact of the operation on the environment, and proposed compensatory or corrective measures.The Prefect and the municipality concerned by the discharges are sent a copy, which the public can consult, at the

[29] Autorisation de rejets d'effluents radioactifs liquides par les usines dénommées UP 2-800 et UP 3-A et par la station de traitement des effluents liquides et des déchets solides, dénommes STE3 sur le site nucléaire de La Hague (Manche), 28 mars 1984.

[30] Arrêtés du 22 novembre 1988 autorisant la COGEMA à rejeter les eaux pluviales dans le ruisseau des Moulinets et dans le ruisseau de Saint-Hélène.

level of the city hall. The draft decision is sent to the company, which has 15 days to address written observations to the concerned ministers.

The DSIN has recently launched a procedure[31] to review downwards the limitations of discharges of radioactive effluents from nuclear sites.

6.1.3. Supervision

The day-to-day monitoring and control of effluents are entrusted to the operator COGEMA itself, which is also charged with monitoring the impact of its discharges on the environment. COGEMA is by law impelled to record the results of its controls and transmit them to State control authorities. This self-control is, in principle, guaranteed by more-or-less independent State bodies, which by inspecting *"unexpectedly"* the La Hague facilities and checking COGEMA's records can *"tell whether* (the limitations) *are departed from."* [32]

Today, such inspections are provided for in Article 28 of the ministerial order of 26 November 1999 and are entrusted to three State bodies. In addition to the monitoring of the impact of radioactive discharges on the surrounding environment of La Hague, the State bodies, among which OPRI (Office de Protection contre les Rayonnements Ionisants), are charged with operations of inspections of COGEMA's monitoring laboratories and controls on the facilities effluents.

According to the DRIRE (Direction Régionale de l'Industrie, de la Recherche et de l'Environnement), such controls were hardly undertaken by any State authorities in the 1960s. It is only in the 1980s that the DRIRE, as regional representative of the national safety authorities, organised inspections at La Hague on regular basis. Of 80 inspections carried out in 1999, *"2 or 3"* inspections concerned the discharges of effluents. However, the fact that the regulation in force provides for annual radioactivity limitation values only, the State control bodies have limited means *"to ensure that such yearly values are complied with, unless it is done through the control of the company's (COGEMA) records."*

It is worth noting that until today, COGEMA has basically set its own *"concentration"* limits of effluents, which the inspectors of the State bodies may control. Things are likely to change in the future. *"Draft ministerial orders"* are said to be under preparation, fixing regulatory *"instantaneous concentrations."*

6.1.4. Radioprotection

The Decree n° 66-450 of 6 June 1966, concerning the general principles of protection against ionizing radiation was amended by the Decree n° 2001-215 of 8 March 2001. The Decree transposed partially the Directive 96/29/Euratom of the Council of the European Union of 13 May 1996, laying down Basic Safety Standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation, nearly one year after the deadline for transposition into national legislation.

In compliance with the European Directive, Article 17 of the Decree of 1966 was modified to take into consideration the new annual maximum dose limit of 1 mSv for individuals (down from 5 mSv).

The transposition of the Directive has had important implications on French radioprotection legislation. Not only did France have to rewrite part of its health and work regulation, it also has to take into consideration new principles introduced by the Directive, such as the justification principle. This principle may be applied to *"new"* as well as to *"existing classes or types of practice"* which *"may be reviewed as to justification whenever new and important evidence about their efficacy or consequences is acquired."*

Responsibility is left to *"individual Member States to ensure compliance with the basic safety standards and the Commission would intervene only if it thought that Member States were not exercising those responsibilities."* [33] This and the ALARA (as low as reasonably achievable) principle, also provided for in

[31] See: http://www.asn.gouv.fr/data/information/arretes.asp

[32] Declarations by the DRIRE about its supervision of La Hague activities are based on private communications with:
- Mr. Seifried, DRIRE Basse-Normandie (Direction Régionale de l'Industrie, de la Recherche et de l'Environnement, i.e. Regional Division of Industry, Research & Environment), 20 April 2001,
- and Mr. Benssassen, DRIRE Basse-Normandie, 23 April 2001.

[33] Answer given by Mrs Bjerregaard on behalf on the Commission (18 November 1997, OJ C 158, 25/05/1998 (p. 77)) to Question E-3278/97 by Undine-Uta Bloch von Blottnitz (V) to the Commission (20 October 1997 OJ C 158, 25/05/1998 (p. 76)).

the Directive, will in all likelihood have considerable consequences on the French present authorisation system for radioprotection.

It is worth noting that to lighten the legislative procedural system, the French Parliament passed a law on 3 January 2001 providing for the transposition of a number of European Directives through simple parliamentary ordinances. Interestingly enough, the Directive 96/29/Euratom was discretely transposed through a governmental Decree in March 2001, either to avoid a public debate on the matter or to keep the decision centralised and under the control of the executive power.

6.1.5. References to International Legislation

Except for radioprotection and the transposition of European directives and specific multinational treaties, French regulation concerning the discharges of radioactive effluents hardly or ever mentions international legislation, conventions or recommendations. Several international agreements today call for more stringent national regulations aimed at reducing if not eliminating discharges of radioactive effluents, especially releases into the sea.

Because most of them are legally non-binding, the French Administration has had a rather contemptuous attitude towards the results of such milestone international conventions.

The London Dumping Convention recognises that *"the capacity of the sea to assimilate wastes and render them harmless, and its ability to regenerate natural resources, is not unlimited"* and that Member States must *"promote the effective control of all sources of pollution of the marine environment"*, including *"radioactive pollutants."*

Within the framework of the Convention for the Protection of the Marine Environment of the North-east Atlantic, the OSPAR Commission called its Member States in 1998 to *"work towards achieving substantial reductions or elimination of discharges, emissions and losses of radioactive substances."* The OSPAR Decision 2000/1, which entered into force on 16 January 2001, even calls for reviewing the *"authorisations"* of discharges.

6.2. OPERATION AT LA HAGUE

6.2.1. Reprocessing at La Hague

The first reprocessing plant at La Hague, the UP2-400 plant for gas graphite reactor fuel, was started in 1966 for civil and military purposes – the investment was covered for one half by the military and for the other half by the civil budget of the Atomic Energy Commission CEA – and operated until 1998, with about 9,350 tonnes being reprocessed. In 1990, UP-3 was brought into operation, and in 1994, UP2-800 as well. These two plants have reprocessed about 12,000 tonnes so far. Table 3 below shows the annual fuel throughputs at the three reprocessing plants in La Hague from 1966 to 2000. The cumulated total of spent fuel reprocessed at La Hague up to the end of 2000 was approximately 21,200 tonnes.

Table 3 Reprocessing History at La Hague Plants by Fuel Cat egory, 1966-2000 (in tonnes)

Year	UP2 (400) (1)			UP2 (800)	UP3
	UNGG	LWR	MOX / FBR	LWR	LWR
1966	52.8				
1967	97.6				
1968	188.7				
1969	227.8				
1970	136.0				
1971	164.5				
1972	250.4				
1973	212.5				
1974	634.5				
1975	441.4				
1976	218.2	14.6			
1977	351.3	18.0			
1978	371.5	38.2			
1979	264.6	79.9	Phenix 2.2		
1980	253.1	104.9	Phenix 1.5		
1981	250.0	101.3	Phenix 2.2		
1982	226.1	153.5			
1983	117.0	221.3	Phenix 2.0		
1984	185.3	255.1	Phenix 2.1		
1985	109.3	351.4			
1986	75.8	332.6			
1987	68.2	424.9			
1988		345.7			
1989		430.3			30.3
1990		331.1			194.6
1991		311.1			351.4
1992		219.9	German MOX 4.7		448.2
1993		353.8			601.4
1994		317.3		258.6	700.4
1995		0.0		758.1	800.6
1996		12.4		849.6	818.9
1997		0.0		849.6	820.3
1998		32.0	EDF MOX 4.9	774.8	821.9
1999		0.0		848.6	712.9
2000				810.3	387.2
TOTAL	**4,896.5**	**4,449.4**	**19.6**	**5,150.0**	**6,688.2**

(1) This doesn't include reprocessing of a small quantity of RNR fuel in AT1, which is part of UP2 of the INB n° 33, between 1969 and 1979.

Source: Various documents and personal communications, COGEMA, 1997-2000

6.2.2. Waste Production of La Hague

As shown in Tables 4 and 5, the reprocessing operations at La Hague produce significant quantities of wastes. Table 4 indicates the quantity of waste that would be produced annually from the reprocessing of

one year's spent fuel output from a 1,300 MWe PWR (around 30 tonnes); Table 5 shows annual quantities of conditioned and unconditioned reprocessing wastes s accumulating on the La Hague site. The year-to-year evolution of those stocks over the past 8 years is summarised in ***Annex 12***.

Table 4 Annual Wastes Arising from Spent Fuel Reprocessing at La Hague of a 1 000 MWe PWR (1)

	Conditioned waste for storage			
	Activity (GBq/an)		Conditioning materials	Volume (m^3/year)
Process wastes	Beta, gamma emitters	Alpha emitters		
Solution of fission products	555,106	(2) 2,775,103	Glass	3
Structural wastes (hulls and nozzles)	74,105	2,775	Cement	15
Sludge from liquid effluents treatment	37,104	2,590	Bitumen	13
Technological waste from zone 4 (3)	$< 37.10^3$	$< 37.10^3$	Cement	5 to 8
Technological waste from zones 3-2	37.10^3	Negligible	Cement	35 to 45

(1) One 1,000 MWe PWR discharges around 30 t of spent fuel annually.
(2) Of which 99.5% of transuranians (less than 0.5% of plutonium).
(3) Zones 4, 3 and 2 are corresponding to a decreasing potential risk of radioactive dissemination.

Source: COGEMA.

Table 5 Waste Inventory at La Hague, Quantities and Volumes (as of the end of 1999)

	Waste inventory		Volume (1)	
	As of 31.12.1999	**Evolution 1998-1999**	**As of 31.12.1999**	**Evolution 1998-1999**
Cumulated amount of spent fuel reprocessed (tons)	15,097.2	+ 1,561.5		
Conditioned wastes				
Bituminised waste (drum)	9,898	+ 93	2,355	+ 22
Hulls and nozzles (drum) (2)	4,249	+ 591	7,435	+ 1,034
Cemented technological waste (drums)	4,311	- 252	4,900	+ 285
Waste contaminated with alpha emitters (drum) (3)	3,958	- 405	495	- 50
Canisters of vitrified waste	6,759	+ 468	1,325	+ 91.7
Unconditioned wastes				
Hulls, nozzles, and other ILW (tons)	2,245.4	- 8.8	2,600	- 10
Magnesium, graphite and metal (m^3)	3,058.8	- 8	3,058.8	- 8
Sludge (m^3)	9,288.0	+ 24	9,288	+ 24
Storage resin (tons)	34.4	- 0,3	???	???
Nympheas resins cartridges (tons)	30.5	- 28.1	???	???
Graphite resins (m^3)	319.0	0	319	0
Low contaminated soil, sludge and metal (m^3)	14,500.0	+ 80	14,500	+ 80

(1) Calculation of volumes by WISE-Paris where not indicated in the inventory colon.
(2) On the total of 4,249 drums of conditioned hulls/nozzles, 2,731 drums (4,780 m^3) are to be re-conditioned in the future compacting ACC workshop (planned for 2001).
(3) Some of these wastes are planned to be re-conditionned.

Source: National Inventories of Radioactive Wastes, *ANDRA, 1999-2000*

6.2.2.1. Low Level Waste (LLW)

Low Level Waste (LLW) in France is radioactive waste with a total activity of less than 3,700 Bq/g and a content of alpha emitters of less than 370 Bq/g. LLW stemming from the contamination of materials used for reprocessing at La Hague has been sent from 1969 to 1994 to the neighbouring final disposal site Centre de la Manche (CSM). During this period, the CSM accepted 1,470,000 containers (527,000 m^3)[34] of low and intermediate level waste issued from reprocessing of French and foreign spent fuel. After the CSM closure in 1994, LLW from La Hague has been sent to a new final disposal site, the CSA (Centre de stockage de l'Aube) in the east of France.

6.2.2.2. Intermediate Level Waste (ILW)

Intermediate Level Waste (ILW) in France is radioactive waste with a total activity of less than 370,000 Bq/g. It is essentially sludge issued from the Effluents Treatment Stations (STE2 and STE3) and hulls and nozzles from the sheared fuel assemblies. Sludge has been conditioned under a bitumised form until 1997 and COGEMA is now developing another conditioning technology for this waste. Hulls and nozzles have been compacted and cemented in containers.

There is no national repository in France for these wastes which are temporarily stored on the La Hague site (STE3 building for bitumised waste and EDS and E/D EDS buildings for cemented waste). As of the end of 1999, 4,249 packages of hulls and nozzles and 9,898 packages of bitumised waste were in storage on the La Hague site. Moreover, 9,288 m^3 (or 39,000 containers equivalent) of sludge have been stored as raw waste and 2,076 m^3 of hulls and nozzles (together with 540 m^3 of some other waste) have been waiting for more than six years to be conditioned. In 1990, the IPSN (Institute for Nuclear Safety) wrote already that it: *"considers that the re-conditioning of sludge contained in the storage silos of STE2 is of high priority due to the risks of contamination of the water table."* [35]

6.2.2.3. High Level Waste (HLW)

High Level Waste (HLW) is radioactive waste from the dissolution of the fuel in nitric acid and recovered after separation of the different radionuclides. The glass logs in which they are immobilised in the R7 (for UP2-800) and T7 (for UP3) facilities of La Hague, contain essentially fission products and minor actinides, or around 99% of the radioactivity of the spent fuel reprocessed. Production rate of HLW at La Hague is around 200 m^3/year (around 130 $m^3$for 1,000 tons of spent fuel reprocessed). As of the end of 1999, a total of 6,759 canisters of vitrified waste were stored in the R7, T7 and NPH facilities of the La Hague site and 608 canisters had been returned to foreign clients as of March 2001.

6.2.2.4. "Curie-swap"

If most of the La Hague foreign reprocessing contracts include return clauses for radioactive waste, they do not include clauses concerning specific categories of waste. To simplify the waste management, COGEMA and its foreign clients agreed to interpret the contract clauses in terms of radioactivity content and not in terms of volume, i.e. they preferred to return smaller volumes of waste with higher radioactivity content over return of waste corresponding to the volumes generated by the reprocessing of foreign fuel. This interpretation of the return clauses leads to the management of huge volumes of foreign intermediate level waste at La Hague and management by ANDRA of the low level waste issued from the reprocessing of foreign fuels at La Hague. The case of foreign waste storage in France is illustrated in ***Annex 13***.

6.2.2.5. Reprocessing at La Hague and HLW long-term management

As in nuclear countries that have chosen the direct disposal option for spent fuel, decisions on definitive solutions for HLW management are yet to be taken in France, as shown in Table 6.

[34] ANDRA, "Où sont les déchets radioactifs en France ?", édition 2000.

[35] IPSN, "Programme de reprise des boues issues du retraitement des combustibles usés entreposées sur le site COGEMA de La Hague", October 1999.

Table 6 Waste Management in France by Category (as of the end of 2000)

	Short lived main elements < 30 years	**Long Lived > 30 years**
Very Low Level Waste	Current studies for application at CSA	Studies on management of mining tailings
Low Level Waste	Surface storage (CSA)	Studies (radium, graphite)
Intermediate Level Waste	Studies on management of tritium contaminated waste	
High Level Waste	Research and Laboratory Site Investigations (under the law of 30 December 1991)	

Source: DSIN, 2001

Only recently, as pointed out in a parliamentary report [Bataille, 2001], it was admitted that some French spent fuel, both uranium fuel and MOX, would also go to final disposal. Final waste volumes to be managed are unfavorable to the reprocessing route also because of the much higher heat output of spent MOX if compared to uranium fuel [Charpin *et al*, 2000]. Spent MOX fuel requires a longer interim storage before its final disposal – some 150 years instead of 50 years for uranium fuel.

6.3. DISCHARGES FROM LA HAGUE

La Hague discharges are set out in Figures 8 and 9. Note logarithmic scales are used in these illustrations in order to deal with the wide range of data points.

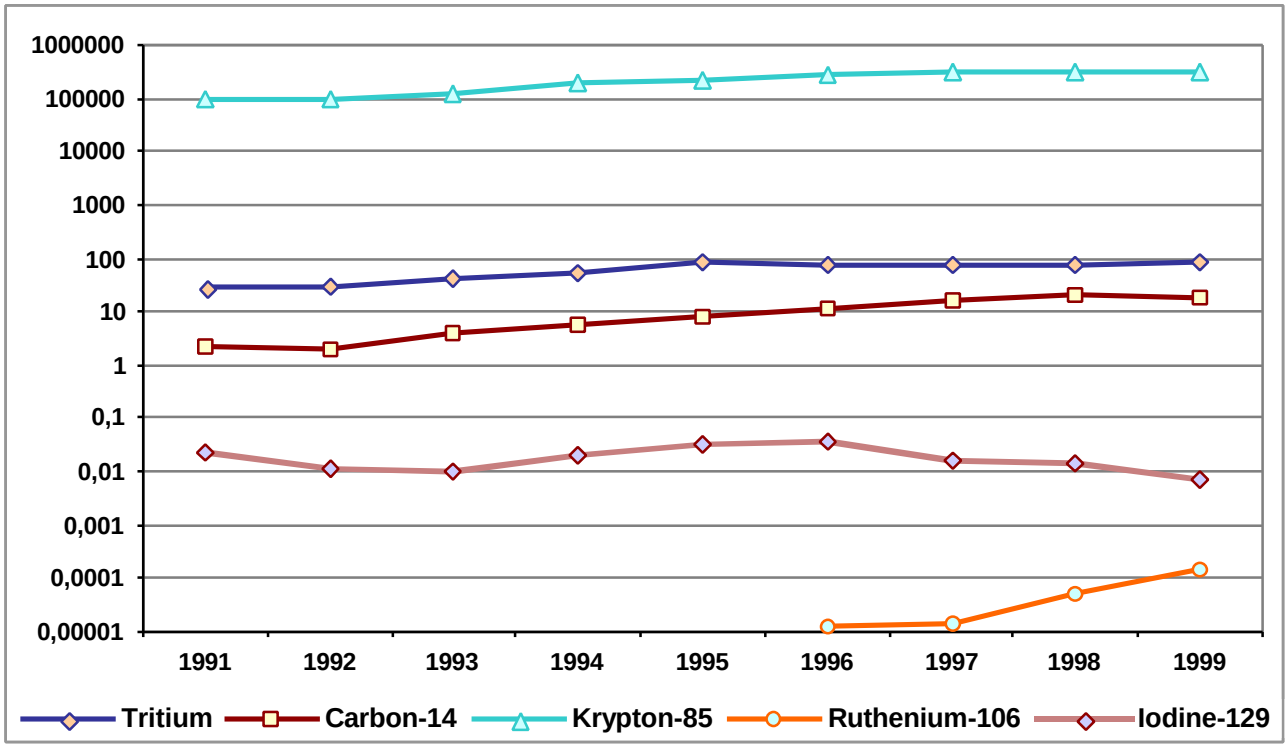
6.3.1. Authorisations

The La Hague site is authorised to release a significantly higher quantity of radionuclides both in marine media and in the atmosphere than any other nuclear facility in France. ***Annex 14*** presents a comparison between the reprocessing plant authorisations at La Hague and two typical French light water reactor sites. The comparison of the authorised release levels at La Hague and a Flamanville reactor, 17 km along the seashore from the La Hague site shows that the La Hague limits are roughly:

- 20,000 times higher for gases, excluding tritium (krypton-85, carbon-14…),
- 1,000 times higher for gaseous and liquid tritium,
- 275 times higher for halogenes (iodine, chlorine, etc)
- 8,000 times higher for liquid beta emitters, excluding tritium, discharge.

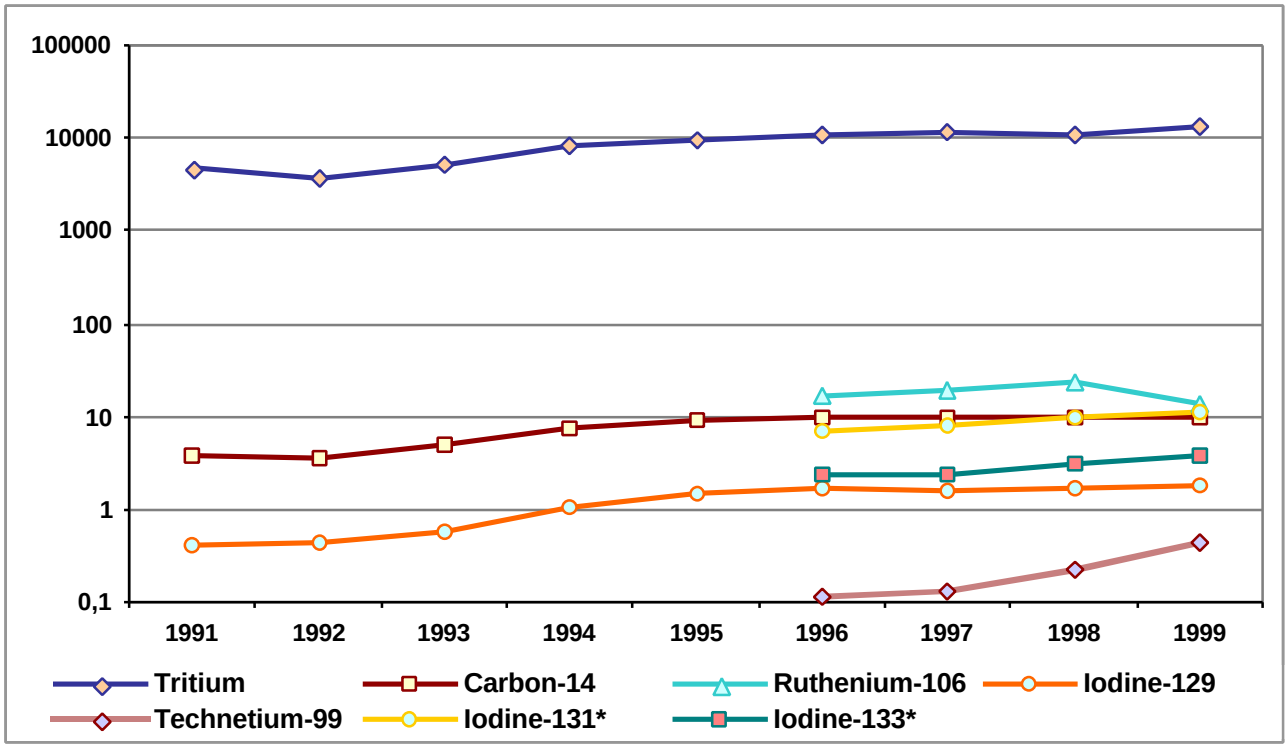
No specific limit exists at La Hague concerning the atmospheric release of alpha emitters while they are prohibited at EDF power plants. Discharges of alpha emitters into water are also prohibited at EDF plants.

Figure 8 Annual Air Emissions from La Hague (in TBq)



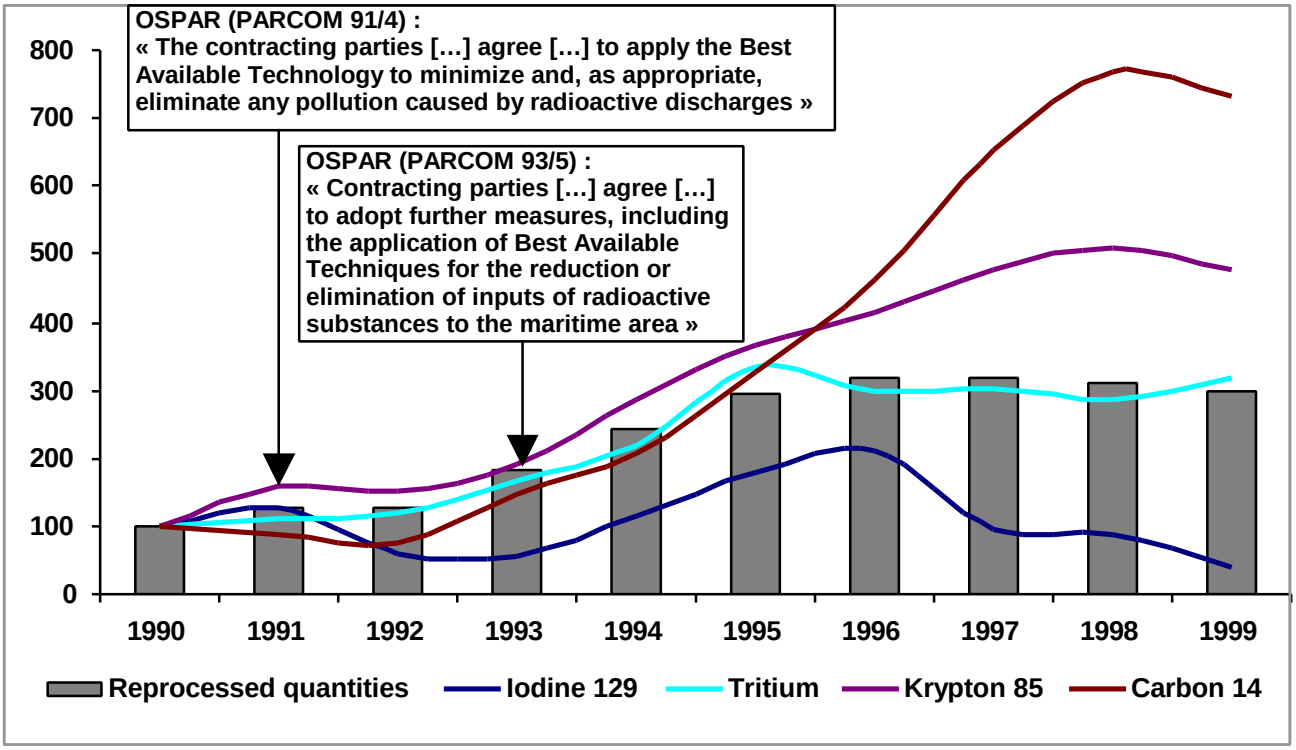
Source: COGEMA [1998], Dossier d'Enquête Publique

Figure 9 Annual Liquid Discharges from La Hague (in TBq)



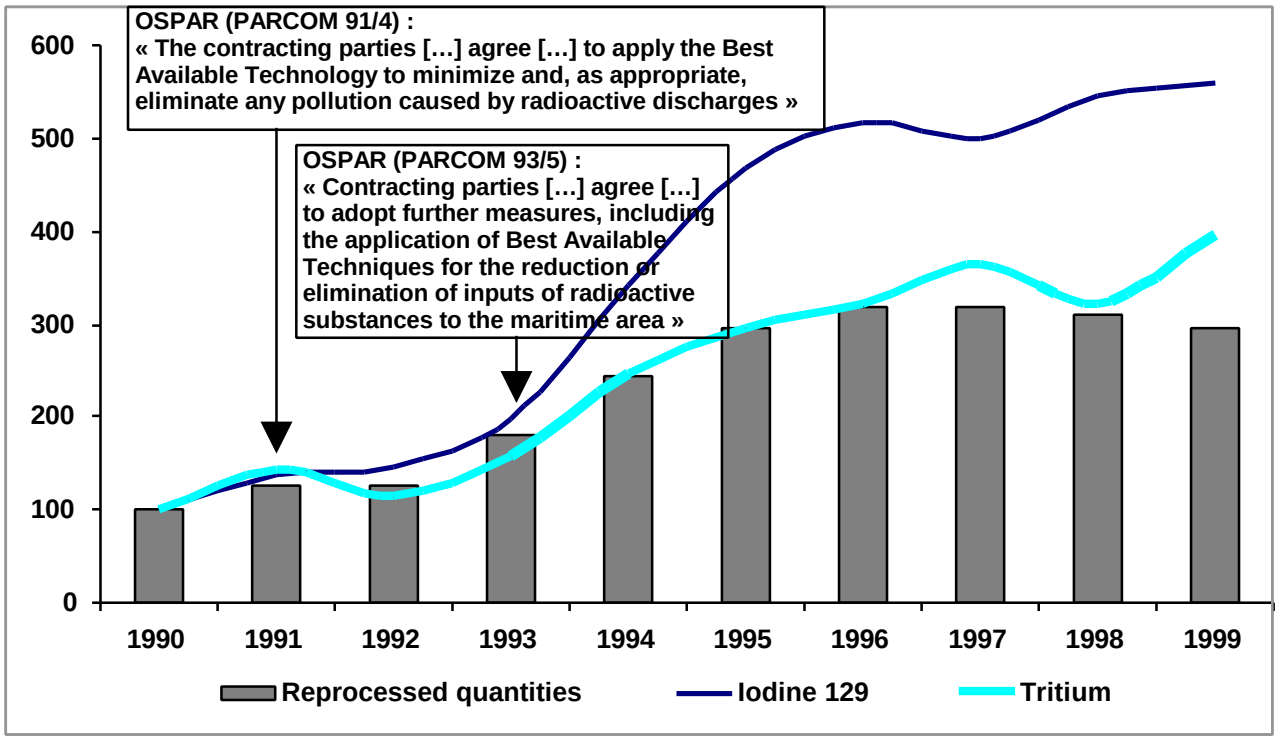
Source: COGEMA [1998], Dossier d'Enquête Publique

Figure 10 Evolution of La Hague gaseous discharges 1990-1999 (index 100 in 1990)



Source: [GRNC, GT-1, 1999]; communication COGEMA, 2001

Figure 11 Evolution of La Hague liquid discharges 1990-19 99 (index 100 in 1990)



Source: [GRNC, GT-1, 1999]; communication COGEMA, 2001

6.3.2. Discharge levels of major radionuclides

Nuclide releases from La Hague are several orders of magnitude higher than those from French power reactors (see ***Annex 15***). In 1999, La Hague released over 7,000 times more radioactivity into the environment than the two light water reactors 17 km along the seashore from the La Hague site.

The UP2-800 plant began to operate in 1994 and the tonnage of fuel reprocessed at UP2 increased by a factor of four within 10 years. The graphs presented in Figures 10 and 11 for major radionuclides illustrate the increased discharges since 1994, in correlation with the increasing production.

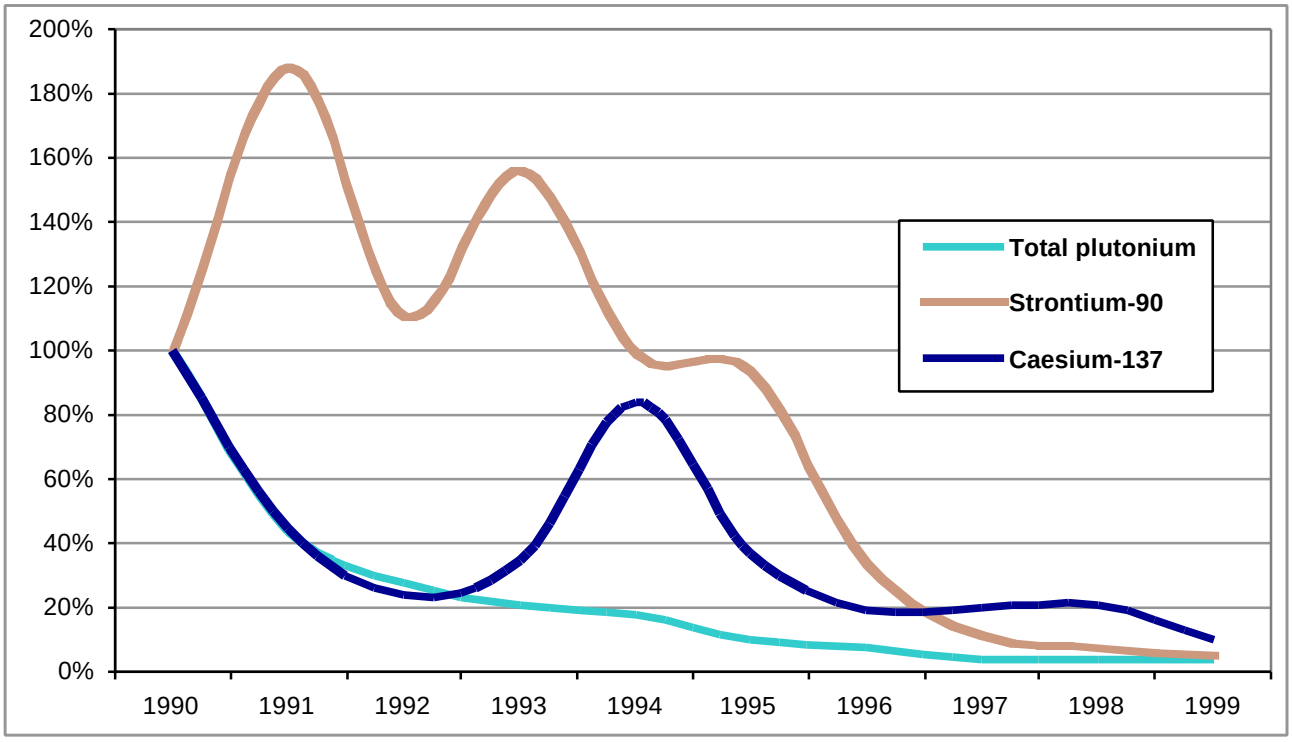
Krypton-85 (^{85}Kr, half-life: 10.7 years) releases have been increased five fold over the last decade, in line with the tonnage throughput.

Carbon-14 and tritium gaseous releases have been increased by a factor of four and three respectively, in the period 1990-1999. These nuclides exchange easily with carbon and hydrogen atoms in living organisms. Carbon and hydrogen, of course, are major constituents of organic matter and hydrogen is a major constituent of water. Gaseous releases of these nuclides have been increasing since the beginning of La Hague operations, and reached a maximum in 1996 for the 1966-1996 period.

COGEMA does not report measurements for gaseous chlorine-36 (^{36}Cl, half-life of 300,000 years), gaseous technetium-99 (^{99}Tc, 214,000 years) and gaseous strontium-90 (^{90}Sr, 28.8 years) releases.[36]

There is a trend towards lower marine discharges of some radionuclides from La Hague (see Figure 12) and marine discharges of technetium-99 exhibit a sharp decrease since 1990 with the phase out of the reprocessing of gas-graphite fuel. However marine discharges of most long-lived radionuclides have increased, in some cases significantly: e.g. iodine-129, chlorine-36, and carbon-14.

Figure 12 Evolution of La Hague plutonium, strontium-90 and caesium-137 liquid discharges 1990–1999 (index 100 in 1990)



Source: [GRNC, GT-1, 1999]; communication COGEMA, 2001

[36] Sellafield releases gaseous Strontium-90 and it is highly likely that La Hague does as well.

6.3.3. Discharge trends

The direct relationship between reprocessing throughput and nuclide discharges at La Hague means that, under current technical conditions, emissions will not decrease without a decline in reprocessing activity. On the contrary, the future conditioning of the large stocks of raw intermediate level wastes might lead to additional radionuclide releases.

6.3.4. Unplanned Radioactive Releases

6.3.4.1. Major accidents and list of incidents at La Hague plant

There have been numerous incidents and accidents at the La Hague plants. ***Annexes 16*** and ***17*** give an overview of a number of examples. Some accidents have led to the release of significant quantities of radioactivity to the environment, in some cases by a factor of 10 or more in excess of the annual limits. In a few cases, doses delivered to workers and/or members of the public have been substantial. For example, as a consequence of a severe discharge pipe break in 1980, individuals of the critical group (fishermen) received approximately 3.5 times the currently authorised annual dose (namely 3,486 mSv, to be compared with the current European limit of 1 mSv/year).

In many cases, a proper evaluation of environmental and health consequences were not carried out at all. However, accidents/incidents are estimated to be responsible of 36% of the leukaemia risk level for the 0-24 year age category around the La Hague site, according to the Radio-ecological Group of North-Cotentin [GRNC, GT–4, 1999].

6.3.4.2. Potential Hazards at the La Hague plant

Neither COGEMA nor any governmental institution in France has published a thorough global risk analysis for the La Hague plant.

The main consequences of hazards likely to be induced at La Hague are:

-public and workers exposure to radiation or to chemical matters during operations,
-dispersion of radioactive materials or chemical products in the environment,
-fires and explosions giving rise to public or workers exposure.

The main sources of potential hazards are listed below:

- Fire and explosions. There is a serious risk of fires and explosions in the storage pools, in the vitrification plants or in the effluent treatment plants at La Hague. The ***Annex 18*** lists the main fires or explosions occurred in the reprocessing plants around the world. A loss of coolant in storage pools could lead to a self-sustained fire that would release large amounts of radionuclides into the environment.
- Caesium-137 (^{137}Cs, half-life 30 years) stocks in the spent fuel pools of La Hague. One ton of reference spent light water reactor (LWR) fuel[37] contains just above 1 kg, or $3.25\ 10^3$ TBq of caesium-137. COGEMA is expected to soon be authorised to enhance the capacity of storage of the pools to 17,600 tons of spent fuel. Considering that 7,508 tHM of different spent fuels are currently stored in La Hague cooling ponds (as of 31 May 2001), the caesium-137 stock in La Hague ponds could be close to 7.58 t, that is 287 times the quantity released by the Chernobyl accident (26.4 kg). The accidental release of the total quantity of caesium-137 stored at La Hague in the marine environment, according to a report commissioned by the European Commission [Dreicer, 1995], would lead to a dramatic regional collective dose of 2 million man.Sv, that would mean an expected 100,000 fatal cancers, according to ICRP risk factors (5% per man.Sv). More calculations of collective doses are presented in ***Annex 19***.
- Separated plutonium stocks at La Hague. Potential risks of dispersion of some of the 50 tons of separate plutonium currently stored at La Hague are not analysed by COGEMA in the public inquiry

[37] Spent UOX fuel with a burn-up of 33 GWd/t, 3.25% of initial enrichment and 3 years of cooling period [GRNC, GT–1, 2000].

report. These stocks raise concern for nuclear proliferation since plutonium is a key ingredient for nuclear explosive devices. Several kilograms are sufficient to manufacture a crude nuclear device.

6.4. ENVIRONMENTAL CONCENTRATIONS AND DOSES

6.4.1. Environmental Concentrations

Radionuclide concentrations in foodstuffs that exceed the EU Community Food Intervention Levels (CFILs) have been only rarely identified in the La Hague environment. Royal crabs caught in the area of the sea discharge point of the La Hague plant were measured in 1997 with strontium-90 concentrations and plutonium exceeding the CFIL respectively by a factor of eight and two (see ***Annex 9b*** for details).

However, only selective samples have been taken until recently and very few radionuclides have been measured before 1990. No measurements at all are available for key isotopes such as carbon-14, or krypton-85 before 1996. Serious efforts to begin completing the range of measured isotopes have started only in 1996/1997. Also, the full range of samples has not been taken systematically every year, but sometimes only as spot checks with very few sites fully sampled. This lead to incomplete series of data and "orphan" sites, both very difficult or impossible to interpret. Sampling redundancy is very low and the few redundant samples sometimes differ in concentrations by a factor of two. This illustrates the absence of a coherent surveillance program of environmental contamination, especially before 1996.

Of the 500,000 measures conducted between 1978 and 1997 and inventoried by the GRNC, 51% have been carried out by the operator COGEMA, 16% by the national marine's department GEA (Marine Nationale – Groupe d'Études Atomiques), which operates a nuclear submarine base at Cherbourg and 17.5% by the national radiation protection board OPRI (Office de Protection contre les Rayonnements Ionisants) [GRNC, GT-2, 1999]. Given the very low share of samples analysed by other institutes (for example ACRO [1997], University of Bremen [1997]), it is worth noting that some of the highest readings were identified by these latter laboratories on some of the least measured radionuclides. This should be an additional incentive to enlarge the redundancy of measurements.

Given the absence of a systematic and coherent long-term sampling and measuring program, it is difficult to carry out a trend analysis of nuclide concentrations in the environment due to the La Hague reprocessing activities. The following historical overview of the La Hague area contamination (Table 7) should therefore be read as a tentative partial analysis only that also illustrates the lack of continuous data series.

Table 7 Overview of peak years of nuclide con centrations in the La Hague environment

Sample type	^{137}Cs, ^{60}Co, ^{125}Sb, ^{106}Ru/^{106}Rh, ^{40}K		^{90}Sr	^{3}H	^{131}I	^{99}Tc
Fucus	1979/80	1984/85	?	?	?	1985
Limpets, mussels, oysters	1980/81	1985/86	?	?	?	?
Drinking water	1979/80	No peak	?	1981/82	?	?
Grass	1980/81	No peak	?	?	?	?
Milk	1980/81	1985/86	1984	1982	1985/86	?
Fishes	1982/83	1987/88	1984	?	?	?

Source: WISE-Paris, 2001, from [GRNC, GT-2, 1999]

Concentration peaks in 1979/1980 vary in intensity depending on the sampling area, the sample type and the measured radionuclide, but reduction factors between 10 and 50 if compared to 1997 levels can be retained. Reduction factors between 5 and 25 if compared to 1997 levels can be retained for the 1984/1985 contamination peaks. Since 1990, measures of contamination seem to indicate a slight but regular decrease of radionuclide concentrations where measured.

The sharp increase in releases of some radionuclides from La Hague to the sea (in particular tritium and iodine-129) and the air (in particular tritium and carbon-14) throughout the 1990s is not really reflected in

the trend analysis because of lacking data. The GRNC conclusions about both carbon-14 and iodine-129 concentrations is that *"there are not enough data to evaluate the representativity and dispersion of the values"* [GRNC, GT-2, 1999]. However, the GRNC concluded for carbon-14 that *"the results of measures in the marine or terrestrial environment superior to 250 Bq/kg show recent anthropogenic contribution."* It also noted *"an increase of iodine-129 concentrations in fucus since 1988."*

6.4.2. Doses from Environmental Radiation

While the official figures have generally shown a very small dose impact from environmental radiation in the La Hague region (see ***Annex 27***), the analysis of the potential impact of more highly contaminated food stuffs, which have rarely been published but have been identified occasionally near La Hague in the past (see previous point 6.4.1), gives a different picture, as illustrated by a study commissioned by the German Office for Radiation Protection (BFS) [Beninschke, 2000].[38]

The Critical Group around La Hague, as defined by COGEMA [2000], the fishers from Goury, have a defined annual uptake (ingested activity for adults corresponding to the nominal discharges) of:

- strontium-90: 8.6 Bq
- technetium-99: 28 Bq
- iodine-129: 44.7 Bq
- caesium-137: 329 Bq
- ruthenium-106: 4,816 Bq
- tritium: 6,722 Bq
- artificial carbon-14: 13,985 Bq

These are very small quantities of radionuclides if compared to concentrations found in the La Hague environment and foodstuffs. The supposed uptake of strontium-90, for example, would be already reached with the ingestion of 1.7 grams of crabs taken close to the discharge point of the liquid effluents. Moreover, the consumption of 320 g of those crabs are sufficient to reach the German dose limit for the red bone marrow. It is therefore plausible that parts of the local population around La Hague has been and is exposed to much higher doses than considered in the official dose estimates.

The cumulative effective dose (adult: 2.3 mSv/a; child: 0.83 mSv/a) induced by the consumption of seafood (especially relevant are the crabs from the vicinity of the discharge pipe[39]), as calculated under German statutory dose assessment assumptions, exceed German and EU dose constraints (0.3 mSv/a and 1 mSv/a respectively).

6.5. IMPACT OF LA HAGUE DISCHARGES – BACKGROUND STUDIES

6.5.1. Marine effects

Long range transport of long-lived radioelements can spread contamination beyond the European continent. The mean residence time of iodine in the atmosphere is 14 days, sufficient to allow contamination of the southern hemisphere, according to [Moran, 1998]. Moran also alleged that global tropospheric circulation could drive the air masses across the Atlantic and could result in transport of iodine-129 from European fuel reprocessing facilities to the continental US. After deposition, iodine-129 infiltrates the soil and is then washed into rivers and other surface bodies.

Water movements in seas adjacent to a source point of marine discharge allows long-lived radionuclides to be transported over long-range distances. Releases from Sellafield reach the Norwegian coast by ocean currents for instance, within two to three years. Higher transfer rates of soluble radionuclides from La Hague compared to Sellafield were observed and explained by a coastal current from the English Channel, along the European coast, to the Norway coastal areas. [Brown, 1998]

[38] Calculations under 6.4.1 from [Beninschke, 2000].

[39] According to certain sources, crabs move up to more than 1 km *per day*. Therefore, the significance of the exact location where they were caught remains unclear.

Discharges of iodine-129, technetium-99, carbon-14 concentrate in marine organisms and sediments. Some recommended values of the concentration factor in various marine organisms, provided by the Groupe Radioécologie Nord-Cotentin (GRNC), are compiled in ***Annex 20***. Long-lived radionuclides such as iodine-129, technetium-99 exhibit the highest concentration factors in seaweed. Seaweed is for instance used in the food processing industry (in ice cream and milk-based products) and in the formulation of cosmetics. In the past, farmers spread seaweed on the soil as fertiliser and used it as animal feedstock. The French independent laboratory CRII-Rad[40]. has stated that these possible transfer patterns should be included in the evaluation of global collective doses. The French National Evaluation Commission (CNE) on research into radioactive waste management [CNE, 2000] raised the specific problem of improving iodine-contaminated waste packaging.[41] The increasing discharges of iodine-129 and tritium from La Hague reprocessing facilities appear to be in breach of France's obligations under the OSPAR Convention.

6.5.2. Health Effects

6.5.2.1. Cancer morbidity inquiry in the Manche Department

In 1983, a 3 year epidemiological study by the Observatoire Régional de la Santé de Basse-Normandie determined the frequency and the distribution of cancer in the region [Collignon, 1983]. Morbidity was found to be higher than expected in the surroundings of Cherbourg for men in case of leukaemia and respiratory organs, and for women in case of leukaemia and lung cancer (see ***Annex 21***). Moreover, mortality data show an increased rate of cancers for the digestive organs in North-Cotentin, and *"only Cherbourg county shows a mortality significantly higher than the regional mean value for men."*

6.5.2.2. Epidemiological study by Viel and Pobel

In 1995, Viel *et al* published the results of a study of the incidence of leukaemia among persons aged 0–24 years living in a 35 km radius around the La Hague reprocessing plant [Viel, 1995]. This study suggested an excess of leukaemia cases in the canton of Beaumont-Hague (corresponding to about 10 km around the plant). Four cases were observed between 1978 and 1992, compared with 1.4 expected. In 1997, Pobel and Viel published the results of a case-control study, which they claimed provided *"convincing"* evidence in childhood leukaemia of a causal role for environmental radiation exposure from recreational activity on beaches.

Two kinds of behaviour were found to be potentially connected with the increase in leukaemia risk:

-the use of local beaches for recreational activities by children and mothers during gestation, and

-fish and shellfish consumption.

In the first case, the relative risk was found to be 2.87 (compared with 1.00 where children or mothers never went to the beach). Ingestion of seafood increased the relative risk to 2.66 (to be compared to 1.00 if no seafood was consumed).

Viel's concluded that *"there is some convincing evidence in childhood leukaemia of a causal role for environmental radiation exposure from recreational activities on beaches"* [Pobel, 1997]. These findings resulted in the French Government ordering a new inquiry by the Radioecological Group of North-Cotentin (GRNC) to look into the leukaemia risks around La Hague.

6.5.2.3. The Radioecological Group of North-Cotentin (GRNC) survey

In 1997, the French Ministry of Land Use Planning and of the Environment and the Secretariat for Health and Social Security commissioned a study by the Nord-Cotentin Region which set up the Nord-Cotentin Radioecology Group (GRNC) for this purpose. The report of the Group in July 1999 [GRNC, 1999] concluded that the number of cases of radiation-induced leukaemia attributable to radiation doses from discharges from local nuclear facilities would be around 0.002. They stated that it seemed improbable that exposures due to discharges from local nuclear facilities would contribute significantly to explaining the

[40] "Contrôles radiologiques sur des organismes marins à La Hague", CRII-RAD laboratory., May 1997.

[41] *"International agreements (OSPAR Convention) lead to think that in future Iodine-129 will have to be held back and its conditioning or an efficient treatment will have to be carried out, this all the more since the very small quantity of Iodine (relative to the entire quantity of generated iodine) contained in intermediate level waste [déchets B] represent the dominating radiological impact at the exutory of an eventual storage"* [CNE, 2000].

elevated incidence of leukaemia observed among the young people aged 0-24 years in the canton of Beaumont-Hague over this period [Rommens *et al*, 2000].

This conclusion is similar to that reached in the UK concerning the increased leukaemia incidence in young children at Seascale near Sellafield. Also, as at Sellafield, important uncertainties exist over the estimation of radiation doses from environmental discharges. The GRNC report expressed reservations over whether conclusions could be drawn without a quantitative analysis of uncertainties; this analysis is now underway [see Simmonds, 2000].

The GRNC report stated that the contribution to doses from nuclear facilities was *"low, regarding the incidence of leukaemia showed by recent epidemiological studies."* Nevertheless, the Group added: *"this result is a mean estimation and it is worth underlining that uncertainty margins were not quantified."*

CRII-Rad Laboratory representatives, members of the GRNC, refused to sign on to the report's conclusions. Their main objections were [CRII-Rad, 1999]:

-the Group excluded investigations into collective doses and the long-term impacts of long-lived radionuclides (including carbon-14, iodine-129, technetium-99);

-high levels of contamination of marine life surrounding the discharge pipe were set apart although local fishing practices give rise to non-negligible exposures;

-only 0,23% of the measurements used in the study were carried out by independent laboratories, and 75% by the operator;

-exposures from radioactive transports was not taken into account: spent fuel is currently moved by train following usual routes, and the public can be exposed to non-negligible doses;

-involuntary transport of radioactive particles by workers to their home was not considered;

-possible evolution of human practices regarding diets and food hsabits was not explored , including possible increased seaweed consumption, and public use of the Sainte-Hélène contaminated stream;

-no analysis on a multi-factorial impact of possible synergistic effects (chemical discharges, non-ionising radiation…) was carried out;

-father exposures to ionising radiation before conception were not studied;

-mother exposures during gestation included routine but not uncontrolled releases of radioactivity (although the latter represent 36% of ex-utero exposures.

The GRNC did not use a collective dose model to assess both leukaemia risk and doses committed towards various reference groups.

In the case of leukaemia, the experts summed up the contribution of routine discharges for a 30 year operational period in terms of individual dose to the bone marrow (not to the whole body). Then, this individual dose was multiplied by, roughly, a definite number of persons, supposedly representative of the evolution of the population of the county between 1966 and 1996.

In the case of the dose evaluation, the GRNC used an individual dose approach that was applied to a reference group. The annual committed doses are presented in ***Annex 22***. COGEMA dose estimates are under 10 micro Sievert (μSv) per year for the two reference groups it has chosen. GRNC calculated an individual dose six times higher than the COGEMA values for four different reference groups (least case: 60 μSv/year).

GRNC did not use a global model to assess leukaemia doses and risks. A global model that takes into account the earth's population truncated at 100,000 years was developed by CEPN in its study for the European Commission [Dreicer, 1995]. This model reflects the collective and long term impact of longer lived radionuclides, than the 30 year estimate by GNRC. Given the 16 million year half-life of iodine-129, an untruncated dose model should really be used (i.e. extending doses to infinity).

6.5.2.4. La Hague Childhood Leukaemia Study 2001

In June 2001, a new epidemiological study extended the earlier Pobel study to include new data from 1992 to 1997 [Guizard, 2001]. In this period, 3 cases of acute lymphoblastic leukaemia were observed while 0.47 were expected.

The key findings were that the study confirmed the earlier findings by Viel and Pobel. The study also indicated that the increased incidence was continuing, and had not stopped. Most important, the study provided more data to allow statistical significance to be established (for the first time in France) for the increases in leukemias at La Hague.

The study *"indicates the predominance of acute lymphoblastic leukaemia over childhood leukaemia cases diagnosed in the Beaumont-Hague electoral ward. Although not conclusive, this observation could be linked to the dramatic intensity of population movement that occurred in this particular area."*

The authors conclude: *"In view of statistically significant clusters of childhood leukaemia near other European nuclear reprocessing sites, and the concerns of the local population, these findings argue in favour of continued investigations in Nord Cotentin. Three lines should be followed: measuring the incidence of child leukaemia among people who have lived at any time in Beaumont-Hague; identifying possible causes of leukaemia in the area (studies of population movements); and measuring the incidence of other diseases the occurrence of which could be linked to radiation (other cancers, and reproductive function disorders)."*

6.5.2.5. "Radiological impacts of spent nuclear fuel management options", NEA, 2000

The Nuclear Energy Agency began in 1995 a comparative assessment between two fuel cycle options, at the request of the OSPAR Commission. This study aimed at comparing from the standpoint of the radiological impact the reprocessing activities and a once-through fuel cycle where spent fuel is not reprocessed.

According to the NEA study, both public and workers exposures could be reduced by about 20% through reprocessing. The report assumes that MOX fuel use avoids extraction of natural uranium in this proportion. However, this is a highly theoretical assumption that has been contradicted by various other sources. A report to French Prime Minister presented in mid–2000 [Charpin *et al*, 2000] indicates that the uranium savings of the plutonium path do not exceed 8%. However, reprocessing operations clearly add a higher collective dose, mainly towards the public.

The NEA Report concludes that *"the differences between the two fuel cycles examined options are small from the standpoint of radiological impact. In this connection, it is simply not justifiable to draw definitive conclusions (…). Consequently, radiological impact is not a key factor favouring one option or the other."*

However this conclusion is contradicted by a number of independent studies [Sumner, 1992; Fairlie, 1997], which found that doses from reprocessing considerably exceeded those from dry storage routes, sometimes by three or four orders of magnitude. Even from cursory examination, it is clear that doses from large discharges of nuclides from reprocessing will exceed the very low doses from dry stores.

And in fact, that is not put into question by the NEA study, as OSPAR Resolution 2000/1 from June 2000 points out: *"Noting further that the NEA study has demonstrated that implementing the non-reprocessing option (dry storage) for spent fuel would eliminate the discharges and emissions of radioactive substances that currently arise from reprocessing it."*

6.5.3. Uncertainties in Dose Assessments

6.5.3.1. A Mandate for the Radio-ecological Group of North-Cotentin to Assess Scientific Uncertainties

Many uncertainties exist in the assessment of doses from discharged nuclides. For example, as regards nuclide inventories, Task Group n°1 of the Radioecological Group of North-Cotentin (GRNC) has stated that it was *"difficult to thoroughly quantify or even to estimate the activity of the radionuclides discharged because of their various behaviours, depending on the step in the process"* and because *"the efficiency of the cleaning treatment of the effluents is not known with high precision for each radionuclide."* (GRNC, 1999) Moreover, estimates are made when measurements are unavailable.

As regards final doses, GRNC Task Group n°4 stated that *"the different steps leading to risk assessment required many hypotheses and approximations that imply an uncertainty surrounding the final results, which is difficult to quantify. (…) It is worth underlining that the uncertainty margins were not quantified."* The GRNC[42] is presently carrying out a sensitivity and uncertainty analysis of the main parameters associated with the leukaemia risk in Nord-Cotentin. So far, it has identified no fewer than 4,000 parameters, including 200 critical parameters, in the methodology used to assess dose impact. A final report is expected to be published later in 2001.

6.5.3.2. Sources of Uncertainties

• Computer codes

Several computer codes exist to determine radionuclide activities in spent fuel. According to J.C. Zerbib[43], senior consultant to the French CEA and a member of the Task Group n°1 of the GRNC, these codes have an error margin of about 5% (up to 10% for some radionuclides). In the case of iodine-129, literature figures range from 170 to 230 grams per ton of spent fuel (a difference of 30%). The lack of an international consensus on these values could result in significantly under-estimated releases.

• Paucity of measurements and environmental monitoring

The CRII-Rad Laboratory has drawn attention to the lack of environmental measurements by the regulatory bodies IPSN and OPRI[44] for many radionuclides [CRII-Rad, 1999]. For instance, technetium-99 and plutonium-241 so far has not been measured in marine organisms by OPRI. No measurements are currently carried out in the vicinity of the discharge pipe by IPSN, and no measurements at all are carried out by the European Commission under Article 35 verification rights.

75% of the measurements available in [GRNC, 1999] were provided by operators which suggests a lack of independent environment monitoring around the La Hague plant. A telling criticism was voiced by a member of the GRNC[45] in the conclusions of the Group's report: *"up to now, measurements were conducted only to check the correct operation of the installations and not in order to monitor health effects on populations."*

• Disputed measurements

Some local practices of fishermen around the discharge pipe have been ignored although of considerable impact on the local population (some hundreds of microsieverts, to be compared with the committed doses of the GRNC scenarios, see ***Annex 22***). Furthermore, M. Guillemette[46] contested measurements by COGEMA in molluscs at the moment of the discharge pipe incident in 1979. As a consequence, the president of the GRNC created a new group of experts that has been focusing for six months on this issue. The impact of the incident was assessed again and the individual dose for a fisherman rose from 0.874 mSv (before rectification) to 3.486 mSv, i.e a four-fold increase. The annual EU limit is 1 mSv for an individual of the public.

• Lack of transparency inside the facilities of COGEMA

Since 1999[47], OPRI has checked COGEMA measurements of marine or gaseous effluents, in a more regular manner. The technical service of the safety authority, the IPSN, also assesses radionuclide concentrations inside the plant on the basis of the operator data, during modifications or the commissioning of a new facility. But all these data are kept confidential.

WISE-Paris studied the very long-lived nuclide, iodine-129 (^{129}I, half-life: 15.7 million years). Using two models (those of COGEMA and UNSCEAR) and values recorded by COGEMA, WISE-Paris quantified the differences between the theoretical iodine-129 activity in spent fuel and the discharged activity to sea or air.

[42] Mandate by the Ministry of Environment and the Secretary of State of Health in a letter dated 24th July 2000.
[43] Private communication, May 2001
[44] OPRI: Office de Protection contre les Rayonnements Ionisants
[45] Monique Séné, President of the GSIEN (Groupement de Scientifiques pour l'Information sur l'Energie Nucléaire).
[46] M. André Guillemette was a previous member of the CSPI (Commission Spéciale et Permanente d'Information) at La Hague. He provided the measurements of the CFDT trade union, in the same location and time as COGEMA's measurements. The CFDT values were 200 times higher than COGEMA's measurements.
[47] Such inspections are carried out in accordance with the ministerial order of 26 November 1999.

Annex 24 compiles the results of these calculations from 1989 to 1999. Large gaps are observed in the beginning of the 1990s, as only 50% of the theoretical values were reported discharged.

The president of the GRNC has agreed that the iodine-129 problem was important enough to justify the creation of a working group under the responsibility of GRNC.[48] Correspondence with Dr. Sugier is presented in ***Annex 25***.

WISE-Paris has assessed the individual dose committed by an accidental release of the "non-attributed" activity for the year 1997 (least case using the UNSCEAR code). We have assumed that all the activity was released either by the atmospheric pathway (uptake by inhalation) or by the marine pathway (uptake by ingestion of seafood). In both cases, the additional committed individual doses reach half of the annual dose that COGEMA alleges to be induced by *all* radionuclides to anyone of the reference group. The committed collective dose from non-attributed iodine-129 in the period 1989- 1999 would be about 2,500 manSv, about the magnitude of a serious nuclear accident such as the Windscale fire or the Kyshtym waste explosion in 1957 (for details of the calculation and references see ***Annex 25***).

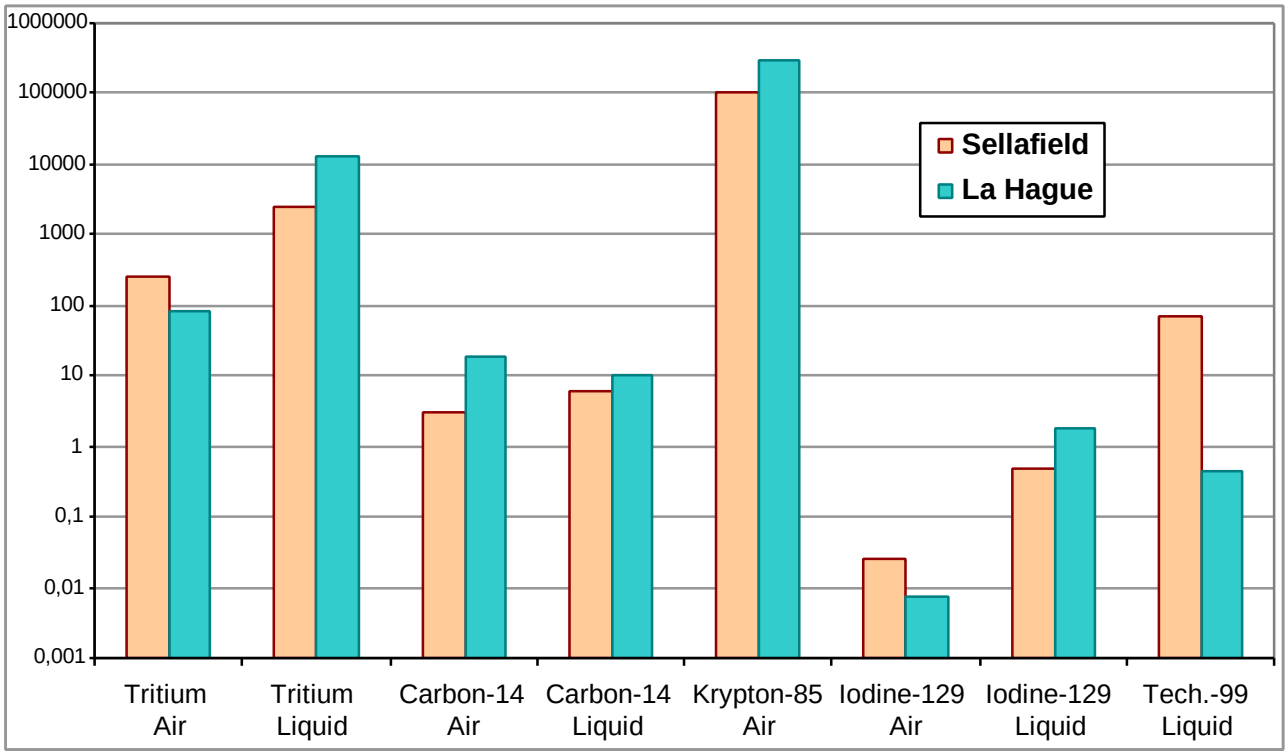
[48] Meeting with Dr. Annie Sugier, IPSN, Clamart, April 27th 2001. The plenary of the GRNC agreed in principle on 29 June 2001 to set up such a working group including experts from IPSN, COGEMA and WISE-Paris.

7. COMPARATIVE AND CUMULATIVE ANALYSIS

7.1. COMPARISON OF RELEASES IN 1999 FROM LA HAGUE AND SELLAFIELD

Figure 13 indicates that in 1999 (a representative year) discharges from La Hague and Sellafield were broadly comparable, except for technetium-99 discharges. In general terms, La Hague discharges were marginally greater than those from Sellafield, except for tritium air emissions, iodine-129 air emissions and technetium-99 liquid discharges. These differences are partly due to the higher fuel throughput at La Hague compared to Sellafield in 1999.

Figure 13 Discharges in 1999 from Sellafield and La Hague (TBq, Logarithmic Scale)



Source: BNFL, 2000; COGEMA, 2001

With Sellafield, discharges have tended to follow the fluctuating fortunes of the site's reprocessing facilities.

In earlier years, it is likely that discharge data was estimated from operating data, i.e. fuel throughputs and burn-ups, as older measuring equipment was often incapable of detecting and/or measuring many radionuclides, including weak beta emitters. Particular difficulties existed with detecting iodine-129 levels given its low specific activity, low concentrations and weak decay energy. In many cases, environmental levels were below the Lower Limits of Detection (LLD) of measurement instruments.

In the case of Sellafield, in the late 1970s, efforts were clearly made to reduce the high levels of nuclide discharges and these were successful in the case of SIXEP and partly successful in the case of EARP. However high radionuclide concentrations from past discharges remain in the environment especially near Sellafield. As will be discussed below, total doses to critical groups near Sellafield are dominated by radiation (>75% of total dose) received from historic discharges rather than current discharges.

7.2. KEY NUCLIDES FOR COLLECTIVE DOSE CALCULATION

7.2.1. Carbon-14

Although carbon-14 discharged from reprocessing is distributed globally, there are significant local increases in concentration. For example, Begg *et al* [1991] have reported that carbon-14 discharged from Sellafield has resulted in an approximate doubling of current ambient concentrations in the Irish Sea. In 1998 and 1999, carbon-14 levels in botanic plants near La Hague as measured by OPRI and COGEMA were 500 to 2,000 Bq/kg (c.f. natural background levels of 250 Bq/kg). Guillemette [2000] states that a level of 2,000 Bq/kg in humans corresponds to an annual dose of about 130 µSv, of which 115 µSv would be due to La Hague carbon-14 discharges. This is an appreciable fraction of the 300 µSv dose constraint usually applied to critical group doses.

Different approaches exist to carbon-14 management at reprocessing plants. For example, the Rokkasho-mura plant under construction in Japan is designed to remove most carbon-14 to atmosphere. At Sellafield, about 27% [Environment Agency, 2001] of carbon-14 arisings are removed in a caustic soda washing column, precipitated as a solid (barium carbonate), then encapsulated in cement [BNFL, 1993b]. COGEMA, which currently releases all carbon-14 arisings from reprocessing, recently stated that carbon-14 abatement was not cost effective in their view [COGEMA, 1999a].

7.2.2. Krypton-85

In 1989, the global inventory of krypton-85 was estimated to be about 3,300 PBq (i.e. $3,300 \times 10^{15}$ Bq) nearly all from reprocessing plants [Kollert and Butzin, 1989]. Since 1989, this will have decayed by about half, but since then a further 2,000 PBq have been discharged from La Hague and 1,000 PBq from Sellafield.

A more precautionary approach to krypton-85 has been adopted in the United States. An NCRP [1975] Report concluded *"…prudence would seem to dictate that fuel reprocessing plants be equipped with krypton-85 removal systems as soon as the technology is practicable."* Since 1983, US regulations have limited releases of krypton-85 to a maximum of 1,850 TBq per 1,000 MW electricity produced, a ten fold reduction from previous practice at the time [NCRP, 1980]. Diethorn and Stockho [1972] from the Nuclear Engineering Department of Pennsylvania State University concluded that *"…although the dose from krypton-85 is small, …there seems to be little justification for continuing the present world-wide practice of dumping it into the atmosphere (…) the only solution for krypton-85 is permanent storage."* Eisenbud [1987] has stated *"if... fuel is reprocessed, 90% of the krypton-85 must be removed for extended storage until the gas has decayed sufficiently for release."*

7.2.3. Iodine-129

Iodine-129 discharges from La Hague during 1975-1992 are estimated to be about 632 kg, and from Sellafield during 1967-1992 about 608 kg: the total from the two plants up to 1992 is therefore about 1.2 tonnes. This is 10 times larger than the total iodine-129 present in the oceans before the nuclear era, approximately 25 times that released by nuclear weapons testing, and several hundred times that released by Chernobyl. [Raisbeck *et al*, 1995]

In the period from 1993-1998, a further 1.4 tonnes of iodine-129 were discharged from La Hague and 0.36 tonnes from Sellafield, i.e. discharges in the 6 years after 1992 were more than in the previous 25 years. Iodine-129 discharged from La Hague and Sellafield in 1999 was eight times greater than the total iodine-129 released by the total fallout from all weapons testing.

In comparison, annual reprocessing emissions of caesium-137 and strontium-90 were never larger than 1% of cumulative nuclear weapons fallout.

Most La Hague discharges follow sea currents through the English channel to the North Sea, and Sellafield discharges flow mostly north around the Scottish coastline then also into the North Sea. Iodine-129 transit time from La Hague to the Norwegian coast is about 3-4 years. Iodine-129 discharges from both Sellafield and La Hague have risen over the past decade by a factor of about five.

7.3. COLLECTIVE DOSES FROM REPROCESSING RELEASES

7.3.1. Collective Doses from Reprocessing

The process of reprocessing results in large-scale releases of long-lived nuclides, which are mobile and are distributed throughout Europe and the world. These nuclides include tritium, carbon-14, chlorine-36, krypton-85, technetium-99 and iodine-129. The European Commission has constructed models, which estimate doses to the UK, Europe and the world from distributions of carbon-14, tritium and iodine-129 nuclides. A rudimentary model also exists for krypton-85, which is assumed to remain a gas and not to interact with the biosphere, lithosphere and hydrosphere. No models yet exist for the global transport of chlorine-36 and technetium-99 although it is understood that the UK NRPB is presently considering a model for technetium-99. Little data exist for the source term of chlorine-36 in spent fuel, and its subsequent environmental transport. This is a subject for future research.

The following tables present European (8a and b) and global (9a and b) collective doses from tritum, carbon-14, krypton-85 and iodine-129 releases in 1999. These have been estimated simply by applying Person Sv/TBq conversion factors to TBq discharges from Sellafield and La Hague in 1999. Relevant conversion factors were obtained from [Simmonds, 1996] and [Mayall, 1993].

Totals are rounded to two significant figures, as global and regional models use parameters whose values are correct only to two significant figures.

7.3.1.1. European Doses

Table 8a European Collective Doses from 1999 Discharges at Sellafield

Nuclide		Dose Coefficient (Person Sv/TBq)	Sellafield Releases (TBq)	European Dose (Person Sv)
Carbon-14	Aerial	7.97	2.9	23
	Liquid	8.33	5.8	48
Iodine-129	Aerial	107.4	0.0025	0.3
	Liquid	481	0.48	230
Krypton-85	Aerial	0.000037	100,000	3.7
Tritium	Aerial	0.0016	622	1
	Liquid	0.0000037	1,800	0.007
Total				**300**

Table 8b European Collective Doses from 1 999 Discharges at La Hague

Nuclide		Dose Coefficient (Person Sv/TBq)	La Hague Releases (TBq)	European Dose (Person Sv)
Carbon-14	Aerial	7.97	19	150
	Liquid	8.33	10	83
Iodine-129	Aerial	107.4	0.0074	0.8
	Liquid	481	1.83	880
Krypton-85	Aerial	0.000037	300,000	11
Tritium	Aerial	0.0016	80	0.13
	Liquid	0.0000037	12,900	0.05
Total				**1,100**

7.3.1.2. Global Doses

Table 9a Global Collective Doses from 1999 Discharges at Sellafield

Nuclide		Dose Coefficient (Person Sv/TBq)	Sellafield Releases (TBq)	Global Dose (Person Sv)
Carbon-14	Aerial	115	2.9	330
	Liquid	115	5.8	670
Iodine-129	Aerial	9,454	0.0025	24
	Liquid	690	0.48	330
Krypton-85	Aerial	0.004	100,000	400
Tritium	Aerial	0.002	622	1.2
	Liquid	0.00004	1,800	0.07
Total				**1,800**

Table 9b Global Collective Doses from 1999 Discharges at La Hague

Nuclide		Dose Coefficient (Person Sv/TBq)	La Hague Releases (TBq)	Global Dose (Person Sv)
Carbon-14	Aerial	115	19	2,180
	Liquid	115	10	1,150
Iodine-129	Aerial	9,454	0.0074	70
	Liquid	690	1.83	1,260
Krypton-85	Aerial	0.004	300,000	1,200
Tritium	Aerial	0.002	80	0.16
	Liquid	0.00004	12,900	0.52
Total				**5,900**

Until recently it had been assumed that collective doses from tritium, carbon-14, krypton-85 and iodine-129 would constitute over 99% of total Regional/Global collective doses from all nuclides released. It is now understood that technetium-99 will also become globally distributed and will add to Regional/Global collective doses. Although no global model has yet been constructed for technetium-99, preliminary estimates by Fairlie and Sumner [2001] indicate that the global untruncated dose from the 70 TBq of technetium-99 released from Sellafield in 1999 might add about 700 person Sv to the total global dose from Sellafield releases, and about 4 person Sv to the European dose. Technetium-99 releases from La Hague are relatively low.

7.3.2. Commentary on Collective Doses from Sellafield and La Hague

The previous tables indicate that, each year, the Sellafield and La Hague reprocessing plants release nuclides that result in a collective dose to Europe's population (600 millions) of approximately 1,400 person Sv. Expressed in global terms, each year, the two plants release nuclides which result in a collective dose to the world's population (6 billion) of approximately 7,700 person Sv. These doses will be delivered gradually over many millennia to future generations throughout Europe/the world.

As discussed in ***Annex 6***, many uncertainties exist over whether these doses will actually occur in the absolute sense. Nevertheless, given the information available to us today and given currently accepted models of radiation effects, these are the best estimates available to us of future radiological detriment from reprocessing releases at the two sites.

7.3.3. Use in Comparative Studies

Because of these uncertainties, it is recommended that the European Parliament should consider collective dose estimates in a relative, rather than absolute, sense. In other words, these estimates should be used as a tool to make comparisons with collective doses from other processes, in order to inform decision-making and policy. The UK NRPB's Board Statement on Radiological Protection Objectives for the Land-based Disposal of Solid Radioactive Wastes [NRPB 1992] has stated (paragraph 73) that comparisons of collective doses from different options were more reliable than absolute values. For example, it stated that collective dose estimates may be used in design studies of planned repositories to compare different options.

Table 10 Global Collective Doses From Anthropogenic Radiation Sources

Source of Exposure	**Global collective dose** (Person Sv)
Chernobyl Accident	600,000
World Nuclear Power Production to 1989	400,000
World Radioisotope Production and Use to 1989	80,000
World Nuclear Weapons Fabrication to 1989	60,000
La Hague Reprocessing for 10 years (1)	**~ 59,000**
Sellafield Reprocesing for 10 years (2)	**~ 18,000**
Kyshtym Accident USSR 1957	2,500
Windscale Accident UK 1973	2,000
World Underground Nuclear Testing to 1989	200
Three Mile Island Accident US 1979	40

(1) Estimated from 5,900 person Sv/year x 10 years
(2) Estimated from 1,800 person Sv/year x 10 years

Source: Bennett, 1995; UNSCEAR, 1993

Similarly with reprocessing, collective doses from discharges may be compared with collective dose estimates from other nuclear-related activities. For example, the European collective doses of 300 person Sv (from Sellafield) and 1,100 person Sv (from La Hague) may be compared with the reference level for releases from Swedish nuclear reactors of 5 person Sv per GWyear capacity.

Other comparisons are made in Table 10 which ranks collective doses from other nuclear processes/accidents with collective doses from 10 years' discharges from Sellafield and La Hague, using figures from the latest available year, 1999. Future life expectancies of these plants is understood to be at least 10 years, based on information from internal industry sources.

7.3.4. Use in Cost/Benefit Studies

To compare costs and benefits of options which have no common comparator (e.g. to compare the costs of new abatement facilities with the discharges they may save), collective dose estimates may be converted to fatalities using the conventional ICRP radiation risk factor of 5% per person Sv, and fatalities may be converted to £, $ or € values using monetary values per statistical life. The two costs may then be compared as occurs in conventional Cost-Benefit Analysis techniques. Conventionally, this procedure is shortened to adopting a £, $ or € value per person Sv saved. Unfortunately the range of values of a person Sv is wide and has been reported as extending from £20,000/person Sv in 1988 prices to £100,000/person Sv in 1990 prices.

The UK Department of Transport value of £700,000 per life has been used in cost benefit analyses in road traffic studies. It is equivalent to a person Sv value of £35,000 using a fatal cancer risk of 5% per Sv. In 1995, the European Commission used a value of £2 million (US $3 million) in its statistical valuation of a life for the external costs of fuel cycles, equivalent to a person Sv value of £100,000 [CEC, 1995]. Indeed, the latter figure is used by BNFL to reflect *"statistical risk and corporate profile"* [Robb, 1990]. These figures are set out in Table 11.

Table 11 Values of Person Sv

Agency	Year	Value Of Statistical Life (£)	Value Of Person Sv (£)
UK NRPB	1991	–	20,000
UK Dep't of Transport	1992	700,000	35,000
BNFL	1991	–	100,000
European Commission	1995	2,000,000	100,000
US NRC	1995	–	133,000

Sources: [CSERGE, 1992; Robb and Croft, 1990; UK Department of Transport, 1992; Robb, 1994; CEC, 1995] and [NRC, 1995; at conversion rate of £1= $1.50]

A reasonable figure for comparison purposes is the figure derived from the European Commission's £2 million value of a human life i.e. £100,000 per person Sv. When applied to untruncated global doses from 10 years' of Sellafield and La Hague releases, the values in Table 12 are obtained.

Table 12 Maximum Values for Optimisation Measures

	Annual Global Doses	Global Doses Over 10 Years	Value Per Person Sv £	Maximum Values £ Billion
Sellafield	1,800	18,000	100,000	1.8
La Hague	5,900	59,000	100,000	5.9

Sources: see Table 11

In optimisation studies (i.e. studies to reduce doses as low as reasonably achievable), expenditure up to these amounts should be considered for remedial or abatement measures to reduce these doses. These are very large sums: the amounts that could be spent on abatement measures comfortably exceed annual operating profits at each site.

7.3.5. Chapter Conclusions

This chapter has derived global untruncated collective doses from annual reprocessing releases at Sellafield and La Hague. In order to assist the Committee on Petitions assess the significance of these doses, this chapter has compared these doses with other nuclear related activities and has valued them using conventional Cost Benefit Analysis techniques.

The results are that global untruncated collective doses from annual reprocessing releases may be seen to be very large relative to other nuclear processes. When valued in monetary terms, the valuations are also very large. For example, they easily exceed the annual operating profits of Sellafield. From these considerations, continued operation of these plants do not appear to fulfil conventional expectations of commercial or radiological justification. Clearly, their continued operation depends on other matters, including social and political factors, which lie outside the scope of this report and remain for the Committee's and the Parliament's consideration.

8. ALTERNATIVE OPTIONS

From a global perspective, the so-called "alternative options" to reprocessing are in fact the preferred options: most spent fuel discharged from reactors worldwide is not reprocessed. The United Nations [UNSCEAR, 2000] has stated that only about 5% to 10% of world spent fuel arisings is submitted for reprocessing: the rest is stored pending final disposal in a repository. Among the countries that operate nuclear reactors, a majority does not reprocess their spent fuel. At national level, most countries have only reprocessed part of their irradiated fuel. Even countries that have made a clear choice and pretend to reprocess all of their spent fuel, like France or the UK, have left large stocks unreprocessed. As of the end of 1998, only 17,000 tonnes of the 30,000 tonnes of spent fuel unloaded from the French reactors (of all types) had been reprocessed [Coeytaux *et al*, 2000].

Most countries are moving towards storage as a medium-term strategy for spent fuel. According to the IAEA [1999], new developments in spent fuel management concern storage rather than reprocessing and dry rather than wet storage.

This evolution corresponds to a clear decline of the rationale for reprocessing. Storage of spent fuel over the medium-term (20 to 40 years) or long-term (>40 years) is increasingly viewed as a more attractive management option than reprocessing spent fuel. This is particularly the case with dry storage compared to wet storage, i.e. in fuel ponds.

8.1. WASTE MANAGEMENT ISSUES

Compared to direct disposal of the irradiated fuel, reprocessing is sometimes presented as a way of sorting waste and recycling valuable resources – i.e. the uranium and plutonium contained in spent fuel. This attractive theory does not stand up to rigorous scrutiny, as recent studies have shown (see below).

8.1.1. Re-use of plutonium and uranium

After the closure of the fast-breeder reactor Superphénix in France (decided in 1997), the use of MOX (mix of oxides of uranium and plutonium) in light water reactors is the only rationale left for the reprocessing of spent fuel. Similarly, the use of REPU (uranium from reprocessing) instead of conventional uranium in fuel is the only way to re-use uranium.

In the UK, there is no program for the use of MOX fuel. In France, 20 reactors have the license to operate a maximum of 1/3 MOX loading. Only two reactors use re-enriched reprocessed uranium fuel.

As of the end of 1998, the French reprocessing program has led to the separation of around 84 tonnes of plutonium contained in French spent fuel, or just more than one third of the total plutonium content of the cumulated unloaded fuel (around 223 tonnes of plutonium in 30,000 tonnes fuel). From these 84 t, only 41.9 t had been re-used at the time, or less than 20% of the total production of plutonium in French nuclear reactors. Some of these results are detailed in ***Annex 26***. The situation is even worse as regards uranium, with only 5.5% of the total uranium content of spent fuel unloaded from French reactors being re-used at the end of 1998 [Coeytaux, 2000].

A recent study, commissioned by the French Prime Minister [Charpin *et al*, 2000] clearly demonstrates the additional cost of reprocessing scenarios. ***Annex 27*** sums up the detailed material and economic balances of the 58 French PWRs (Pressurized Water Reactors), from the first year of operation in 1977 to the theoretical shut down of the last reactor in the years 2040s. One key result of this study is to show that, over the lifetime of operating reactors, reprocessing could only reduce by some 15% the quantities of plutonium in final waste, assuming that all MOX fuel and some of the uranium fuel would not be reprocessed – as it is presently the case. This allows for an economy in natural uranium of around 8%. These results are obtained at very high cost. Each ton of plutonium that is effectively avoided through reprocessing/reuse and not going into final disposal costs about 1 billion FRF.

8.1.2. Final volume of waste

Reprocessing requires the final disposal of vitrified wastes ***plus*** the direct disposal of some spent fuel, and various additional wastes produced through reprocessing, such as bituminised waste, hulls and nozzles, technological waste, and most separated plutonium and uranium which is not re-used. Not only does the direct disposal option produce fewer waste categories, it also produces smaller volumes of final waste. Spent MOX fuels have much higher heat outputs than spent uranium fuels, and thus require much longer storage times before disposal and/or much larger volumes in any final repository.[49] These factors imply much larger costs for handling spent MOX fuel than ordinary uranium fuel.

According to preliminary specifications defined by ANDRA in 1998 for final disposal in a deep ground repository in clay,[50] the same type of small galleries – only with different lengths – could be used to store either canisters of vitrified waste, or UOX or MOX spent fuel. One gallery could receive 8 canisters of vitrified waste, or 4 so-called S3U packages, each containing 3 assemblies of spent UOX, or 2 SM packages, each containing 1 assembly of spent MOX. The respective length of the galleries would be around 20, 28 and 17 m; the volume of one package (including overpack of the canister) is around 0.5, 4.1 and 1.9 m^3. Assuming that the reprocessing of one UOX assembly in La Hague produces around one canister of vitrified waste, these ANDRA concept lead to the following volume orders:

- Disposal of vitrified waste from the reprocessing of 1 UOX assembly:
  0.5 m^3 of package, 12.5 m^3 of package plus structure;
- Direct disposal of 1 spent UOX assembly:
  1.4 m^3 of package, 11.5 m^3 of package plus structure;
- Direct disposal of 1 spent MOX assembly:
  1.9 m^3 of package, 42.5 m^3 of package plus structure.

These results can be used for a basic comparison of the two options: (a) the direct disposal of 8 UOX and (b) the reprocessing of 7 UOX plus the direct disposal of 1 MOX.[51] For 8 assemblies, the reprocessing option only produces 5.5 m^3 of HLW, while the direct option produces 11 m^3. But, if including the volume of the structures in the calculation, the ratio is of 92 m^3 for direct disposal against 130 m^3 for reprocessing. Again, this is not taking into account the additional waste in the reprocessing option, like unrecycled uranium, technological and process ILW from reprocessing, etc.

8.2. ECONOMICS OF DIRECT DISPOSAL VS. REPROCESSING

The economic advantages of direct storage of spent fuel versus reprocessing are considerable. In simplified terms, reprocessing may be viewed 2 to 3 times more expensive than wet storage, and wet storage about 4 to 20 times more expensive than dry storage. It is not surprising that, in worldwide terms, nuclear utilities are moving towards dry storage solutions, including utilities in the US, Canada, Germany, Russia and many eastern European countries.

Comparative costs studies of storage and reprocessing routes conventionally require examination of the costs of all stages of the fuel path from reactor discharge through to final (often termed "direct") disposal in a permanent repository. Four major studies have examined these matters: the German utilities studies, the OECD/NEA study, the EWI study at the University of Köln, and the recent Charpin study in France. Their main results are presented in Table 13 after they are briefly summarised.

• **German Utilities Studies** . Main German utilities studies were carried out by three German institutes, Rhine-Westfalische Energie (RWE) utility, Vereinigung Deutscher Elektrizitätswerke (VDEW) the German Fuel Industry Association, and Projekt Andere Entsorgung at the Kernforschungszentrum Karlsruhe (PAE-

[49] Belgian radioactive waste management schemes envisage 3 times the volume in final storage for spent MOX than for spent uranium fuels. The costs are correspondingly higher.

[50] Communication by ANDRA, 2000.

[51] This is assuming that the reprocessing of 7 UOX produces the right amount to produce 1 MOX, that 7 UOX + 1 MOX deliver as much energy as 8 UOX and that in the reprocessing option all UOX and none of the MOX is reprocessed.

KfK), a government-funded research agency in the early 1990s. These predicted direct disposal would be approximately 50% (RWE and PAE-KfK) to 70% (VDEW) less expensive than reprocessing.

Other national studies agree with these studies. A report by the German Federal Rechnungshof [BRH, 1993], the national parliamentary audit office, stated that reprocessing had become twice as expensive as storage, and that reprocessing was no longer feasible. In a report prepared for the Irish government on THORP, Berkhout [1993] estimated, using conservative assumptions, that dry storage/disposal costs were approximately half reprocessing/disposal costs.

• **OECD/NEA Study**. In 1994, the OECD/NEA examined levelised lifetime fuel cycle costs [OECD/NEA, 1994]. The report was concerned to develop fuel costs averaged over the whole fuel cycle. The consequence was that relevant costs were calculated on a lifetime basis and not discounted to a start up date. This resulted in reprocessing and once through costs being about equal.

However the chairman of the OECD Expert Group which drafted the report refuted the report's main conclusions [NuclearFuel, 1995a]. The chairman, Dr. David Groom of UK's Nuclear Electric (now British Energy), stated that back-end costs were not spread over the whole fuel cycle, and that reprocessing costs were incurred immediately. On the other hand, most storage, and all encapsulation and disposal costs would occur many years hence and could be discounted at 5% over decades. COGEMA, whose directing manager was chairman of OECD's Steering Committee for Nuclear Power, replied stating that discounting to this extent was inappropriate [NuclearFuel, 1995b]. This issue remains unresolved by the OECD.

The figures that reflect the view taken by the Chairman of the Expert Group are as follows: with $340 per kg HM (range $85-410), direct disposal is more than twice cheaper than reprocessing, which total cost is $775 per kg HM (range $565-830). This approach is preferred as it reflects more accurately the position of utilities and governments faced with the decision between storage and reprocessing. The figures indicate that in the reference case the predicted costs of the storage route were less than half the predicted costs of the reprocessing route.

The main conclusion reported by the chairman of the OECD Expert Group was that storage was predicted to be half the cost of reprocessing. Nevertheless, the OECD report was criticised by the EWI report [Hensing and Schulz, 1995] – see below – for unrealistic assumptions, which substantially reduced reprocessing costs. These included the postponement of reprocessing to the year 2006, high uranium prices, new reprocessing plant being built, a low price for reprocessing services, and a low price for MOX fuel fabrication. In addition, the OECD report used a positive value for plutonium ($5,000/kg) and uranium ($33-$135/kg) extracted from reprocessing. These assumptions were (and are) not widely followed.[52] For these reasons, OECD estimates of reprocessing costs are considered to have limited applicability.

• **EWI Report**. The Energie Wirtschaftliches Institut (EWI) at Köln University evaluated various waste disposal options from the viewpoint of a nuclear utility [Hensing and Schultz, 1995]. The EWI Institute has close working contacts with the German nuclear industry. The study carried out a comprehensive financial appraisal of both the storage and reprocessing routes using a zero discount rate. It concluded that direct disposal had a clear cost advantage over the reprocessing option with the disposal cost option being 48% lower than that of reprocessing option. Calculated over the German nuclear industry, the cost advantage amounted to 31.5 million DM or $20 million per year. The report stated that its estimated disposal costs were lower than those calculated by the German Fuel Industry Association due to assumed higher fuel burn-ups in the EWI scenario.

• **Charpin Study**. The recent study commissioned by the French government [Charpin *et al*, 2000] illustrated the additional cost of reprocessing plus MOX scenarios. The "all reprocessing" scenario produced additional costs of FF39 billion, in comparison with the "abandonment of reprocessing in 2010" scenario, representing FF800 million per year of remaining power plant life. The storage option was much less costly: total savings compared to the reprocessing scenario were FF164 billion (5.5% of total cost), i.e. a saving of more than FF2 billion per year over remaining power plant life, or around FF2.7 billion per GWe. This saving is reflected in total average cost per kWh of 13.65 centimes, 0.5 to 1.5 centimes lower than average costs in other scenarios (see ***Annex 27***).

[52] The French utility EDF, for example, attributes a zero monetary value to its plutonium stocks.

• **Comparison of costs per kWh**. Table 13 below sets out results of studies, which have compared costs per kWh of storage/disposal and reprocessing options. Strictly speaking, these studies are not comparable because of different assumptions employed and different values in currencies at various times, however the ratios in the final column may be compared. Storage/direct disposal is consistently less expensive than reprocessing, whichever method, part of the fuel cycle, or discount rate is used.

Table 13 Fuel Cycle Costs (1)

Study	Stages compared	Discount Rate	Reprocessing	Direct Disposal	Ratio Reprocessing to Disposal Costs
KfK/EWI [1984]	Back-end	0%	0.56	0.38	1.47
OECD/NEA [1985]	Complete fuel cycle	5%	>2.17	1.97	<1.10
Fichtner [1991]	Back-end	0%	0.97	0.63	1.54
VDEW [1993]	Back-end	0%	1.53	0.91	1.68
OECD/NEA [1994] (2)	Complete fuel cycle	5%	1.25	1.09	1.15
OECD/NEA [1994] (3)	Back-end	5%	0.36	0.15	2.40
EWI [1995]	Back-end	0%	1.064	0.718	1.48
Charpin *et al* [2000] (4)	Back-end	0%	1.82	0.99	1.83
	Complete fuel cycle	0%	4.68	4.02	1.16

(1) Pfennig/kWh 1994, current prices in year of study, except OECD- in 1991 $, Charpin *et al* in 1999 FF.
(2) Reference case reported as "lifetime levelised fuel cycle costs".
(3) Reference case reported in tables 5.7 and 5.8 of the OECD report as sub-totals for the back-end of the fuel cycle. These figures, calculated by discounting to the year 2006 using a 5% discount rate, were explicitly referred to by the chairman of the OECD study group in his intervention [NuclearFuel, 1995a] following the publication's report. The disjunction between discounted and lifetime levelised estimates is not discussed in the OECD report.
(4) This study is not centred on the fuel cycle, but calculates detailed costs of the nuclear option over the French nuclear fleet operational lifetime. The general results of this study are detailed in ***Annex 27***.

Sources: VDEW – as reported in Nuclear Fuel [1994], [NEA, 1994; Hensing and Schultz, 1995; Charpin et al 2000].

8.3. DRY STORAGE

For nuclear waste management policies, an important issue is the degree to which dry storage may be considered a viable long-term option for managing spent fuel. Dry storage in inert gas presents relatively few theoretical or practical difficulties. The IAEA has concluded after reviewing national experiences of dry storage that it is an acceptable waste management option for the storage of spent fuel for periods of 50 to 100 years [IAEA, 1996]. By this time heat rates will have declined by about two orders of magnitude. The anticipated longevity of dry stores (50 to 100 years) is expected to exceed that of wet stores [Schneider and Mitchell, 1992a]. It is concluded that passive dry storage systems appear to be an acceptable means of managing spent nuclear fuel in the medium to long term. When reprocessing and dry storage are compared, large differences in costs become apparent: the former are clearly greater than the latter. US/Canadian storage systems are less expensive than European systems: US dry storage systems for PWR fuel are estimated to be 8 to 20 times less expensive per tonne than reprocessing [Supko, 1995; Wisconsin PSC, 1994].

Dry stores are considerably less expensive to construct and to operate than wet stores: annual costs are about a factor of 4 lower. Dry stores also seem to have a much higher acceptability than any other spent fuel management option. Environmental and local groups in some countries have not opposed dry storage developments. This was evidenced by the 1987 agreement among major UK environmental groups, supported by over 40 regional and local groups, to a collective strategy of long-term on-site storage. During the 1992-1994 UK public inquiry into Scottish Nuclear's dry storage plans [Hickman, 1994], no environmental group made representations against the plans. Dry storage technologies and economics are detailed in ***Annexes 28*** and ***29*** respectively.

9. POLICY OPTIONS

The following outline of policy options for the official actors involved in the reprocessing industry is based on a first set of suggestions contained in the Intermediate Report of 2 April 2001. The STOA Study Group has invited comments on these proposals, in particular from MEPs, but has received few responses. The options have been modified and further options added in order to take the development of the project and the comments received into account.

The STOA Study Group has identified five main areas of concern:

- Releases of Radioactive Wastes and Their Effects on the Environment and Health
- Management of Non-Discharged Radioactive Wastes
- Management of Plutonium Stocks
- Development of Spent Fuel Management Alternatives
- Development of Democratic Decision Making Tools

Following comments during the Scoping Meeting and the presentation of the Intermediate Report, the research has been focussed on the evaluation of environmental and health effects. However, on each of the areas identified, we look at policy options for the European Parliament, the European Commission, the European Council of Ministers, the Governments of Member States and the Nuclear Industry.

There are a certain number of possible policy options that are applicable for all of the five areas identified. The European Parliament has passed a certain number of resolutions on the issue of nuclear reprocessing and associated matters (i.e. nuclear transports). It is unclear under what procedure the European Parliament has followed up the application of its resolutions and its effects. The European Parliament might wish:

1. to reflect on a clearly defined **mechanism** in order to periodically evaluate the follow up of its resolutions by the relevant institutions;
2. to clarify what **time frame** is allocated to its requests, in particular to the European Commission and the European Council;
3. to reflect on procedures that better take into account the **interactions** between issues and therefore the different parliamentary committees (in particular Industry, External Trade, Research and Energy, Environment, Public Health and Consumer Policy, Budgets).

Possible policy options concerning specific issues:

9.1. RELEASES OF RADIOACTIVE WASTES AND THEIR EFFECTS ON THE ENVIRONMENT AND HEALTH

The reprocessing industry releases very large amounts of radioactivity into the environment. A certain number of measures have been taken in the past in order to regulate and limit these discharges. Other measures to further reduce discharges are as follows: The application of Best Available Technology (BAT) is already required under decisions taken by signatory countries of the OSPAR Convention (of which 12 are EU countries). The decisions taken by the Copenhagen meeting of OSPAR in July 2000 require a review of current authorisations for discharges from reprocessing facilities *"as a matter of priority"* with a view to *"implementing the non-reprocessing option (for example dry storage) for spent nuclear fuel management at appropriate facilities."* The European Commission and the reprocessing countries France and the UK abstained from voting on this decision, while the other 10 EU countries voted in favour.. Nevertheless, it is clear that neither BAT nor the Copenhagen decision is being applied at Sellafield and La Hague. Therefore the following Policy Options should also be considered.

4. The European Parliament should consider ways of encouraging the European Commission to press for the interests of the large majority of EU countries by limiting radioactive discharges from reprocessing plants.

5. The reprocessing industry should respect decisions taken under internationally binding conventions to put into practice BAT in order to decrease significantly radionuclide releases.

6. National regulatory agencies should require the reprocessing industry to respect the decisions taken under international conventions and in particular under OSPAR.

7. The European Commission, while it has published a Recommendation on the application of article 37 of the EURATOM Treaty,[53] has not demonstrated that it is in a position to guarantee that Member States respect the basic safety standards (96/29/Euratom). The European Commission should clarify in its public statements on environmental and health impact, and in its answers to MEPs in particular, to what extent its conclusions are based on its own expertise and to what extent they are depending on Member States' data.

8. The European Commission should require Member States to make public the general data on which its opinions are based. Specific parts of the data, whose commercially confidential nature must be justified, can be deleted from the documents.

9. The European Commission, as envisaged, should carry out its own sampling and measurements in the framework of its Article 35 verifications.

10. The European Parliament should strongly support efforts by the European Commission to increase its verification capacities under Article 35, including in the budgetary decision-making.

11. Operators and supervisory agencies should be obliged to increase the number of radionuclides measured in effluents - in particular in gaseous effluents at La Hague- and their concentrations in the environment.

12. The European Commission should publish its evaluation of the health impact of radioactive discharges into the environment at Sellafield and La Hague, in particular based on information transmitted by Member States under Commission Recommendation 2000/473/Euratom. The data published should include the details of dose calculations and justified uncertainty margins.

13. The European Council should follow up on Euratom Directive 96/29 on radiation safety standards. Implementation in Member States was to have occurred before 13 May 2000. Article 6 (2) says that *"existing classes or types of practice may be reviewed as to justification whenever new and important evidence about their efficacy or consequences is acquired."* Current licensing requests by COGEMA for its La Hague facilities as similar requests for various facilities at Sellafield should be examined according to the justification principle.

14. Some long-lived mobile radionuclides from Sellafield and La Hague result in the long-term contamination of Europe and the world. For example, iodine-129 has a half-life of some 16 million years. Dose assessments in the framework of licensing procedures should always be conservative in order to protect current and future generations. The European Commission should take this aspect into account when considering guidance on *"realistic dose assessments"* under Article 45 of Euratom Directive 96/29. Member States should modify licensing procedures of nuclear facilities to require the transparent evaluation of collective doses from radionuclide releases for all affected populations over untruncated time periods.

15. The European Commission should investigate in detail and report to the European Parliament on the extent to which the global and long-term natures of nuclides discharged by Sellafield and La Hague facilities have been taken into account.

16. The European Commission should give detailed consideration to expressing acceptable limits (for exposures to nearby residents) in terms of nuclide concentrations in biota and foodstuffs, as well in terms of doses. This would be similar to Community Food Intervention Levels (CFILs) used in the case of acute releases.

[53] 1999/829/Euratom.

17. The European Commission and Member States should encourage more research on the distribution and dosimetry of low energy nuclides particularly within cell nuclei.

18. Results from the quantitative analyses of uncertainties in radiation doses and risks in the La Hague area, underway at present, should be made widely available. A similar study should be carried out for the area around Sellafield.

19. European Parliament should call for: (i) appropriate treatment in the ongoing Marina study of factors such as uncertainty, variability and the potential for re-mobilisation of radionuclides from sediments; and (ii) an ongoing process for review of, and input to, the Marina study.

20. The European Commission should examine the impact of chemical discharges from Sellafield and La Hague into the environment and their potential synergies with radionuclide releases in risk assessments.

21. The European Parliament (through STOA) should convene a conference, as recommended by the German Office of Radiological Protection (BfS), to discuss national dose models and model assumptions, given the apparent variation in doses estimated by models used by national regulatory agencies in Europe.

22. Statistically significant increases in the incidences of childhood leukaemia near Sellafield and La Hague continue to the present day. To date, no conclusive causal link with doses from environmental radioactivity has been established by national radiation authorities. Nevertheless, it cannot be excluded that radionuclide releases from the reprocessing plants are the initiating and/or contributing factor. Significant uncertainties remain, in particular in the areas of cellular dosimetry and environmental dose assessments.. Under these circumstances, the continued release of large quantities of radionuclides is clearly inconsistent with the Precautionary Principle. The European Parliament should consider requesting an immediate moratorium on further radionuclide releases to the environment until these uncertainties have been elucidated.

9.2. MANAGEMENT OF NON-DISCHARGED RADIOACTIVE WASTES

The Agenda-21, part of the Rio 1992 Convention, in its Chapter 22 asks that the States *"should not promote or allow the storage or disposal of high-level, intermediate-level and low-level radioactive wastes near the marine environment unless they determine that scientific evidence, consistent with the applicable internationally agreed principles and guidelines, shows that such storage or disposal poses no unacceptable risk to people and the marine environment or does not interfere with other legitimate uses of the sea, making, in the process of consideration, appropriate use of the concept of the precautionary approach."* There are vast amounts of waste stored and disposed of at Sellafield and La Hague.

23. The UK and France should provide evidence that the storage and disposal methods at Sellafield and La Hague are in accordance with the letter *and* spirit of Chapter 22 of the Agenda-21.

24. Generally, Member States should adopt a responsible attitude towards the management of spent fuel options. In particular, national regulatory agencies should implement policies requiring that passivity of spent fuel forms be addressed by utilities. Passivity involves the adoption of spent fuel policies whereby the final waste form requires the least inputs for human intervention and control, including posing reduced threats from diversion and proliferation.

25. The European Parliament should introduce a proposal for legislation prohibiting the import of foreign radioactive waste or spent nuclear fuel into any Member State without prior authorisation to process the material.

9.3. MANAGEMENT OF PLUTONIUM STOCKS

The Euratom Safeguards Agency is at the limit of its capacities, mainly stretched by the inspection effort dedicated to the plutonium industry. Euratom's former Safeguards Director recently declared at an international plutonium conference that *"despite the overwhelming need for verification in the nuclear field, governments and the EU Commission are unwilling to commit the necessary resources."* It is of utmost importance that:

26. the European Parliament and the European Commission make sure that the Euratom Safeguards Agency has the appropriate funding to carry out its mission of verification. The level of appropriate funding should be determined and periodically reviewed in a joint working group between representatives of the Parliament, the Commission and Euratom Safeguards.

27. the European Parliament, in order to reduce the global nuclear proliferation risks, considers the introduction of legislation to prohibit the separation of plutonium unless the utility can demonstrate a short term use of the separated plutonium.

9.4. DEVELOPMENT OF SPENT FUEL MANAGEMENT ALTERNATIVES

In comparison with reprocessing, the long term dry storage of spent fuel appears to be a more safe, less expensive, and less problematic option. In principle, the European Directive 85/337/EEC provides an appropriate tool to require an analysis of alternative options to a given project. However, current licenses of Sellafield and the ongoing licensing procedure at La Hague have not addressed the issue of alternative options. Therefore, further Policy Options are

28. the European Commission should request Sellafield and La Hague operators to carry out appropriate analyses of spent fuel storage and publish the results.

29. the European Parliament should initiate a follow-up evaluation of the performance of non-reprocessing versus reprocessing options (for example, initiative report, new STOA project…);

30. the European Commission and the European Parliament should reorient funding from plutonium fuel technologies to non-reprocessing options in order to guarantee the availability of appropriate R & D results to enlighten the further decision-making process.

9.5. DEVELOPMENT OF DEMOCRATIC DECISION MAKING TOOLS

A recent parliamentary report suggested that a directive should transpose into EU legislation the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (25 June 1998). Directive 96/29 Euratom having omitted to provide for an open access to safety and other fundamental technical reports, the public has had only limited access to information in relation with nuclear activities, despite the fact that many European institutional bodies have repeatedly called for more transparency concerning this matter.[54]

Similarly, the present EU regulation does not provide for a systematic dissemination of information to local authorities about convoys transporting radioactive materials. While it is stipulated in the Parliamentary Resolution of 13 March 2001 on the Safe transport of nuclear material, that *"the local and public authorities legally and operationally responsible for the safety of persons and goods must be informed in advance of transitory convoys"* transporting notably *"nuclear materials."*

Finally, while nuclear activities concern primarily local communities, little has been done so far at the EU level to include their opinion and perspectives in the nuclear energy policy, outside the public inquiries at the environmental impact assessment stage. Here again, Articles 6, 7 and 8 of the Aarhus Convention could provide an appropriate legal basis for future legislation in the field of public access to environmental decision making. Accordingly,

31. the European Parliament should pursue its efforts to initiate the transposition of the Aarhus Convention into European legislation;

32. the European Parliament should carry out an evaluation of the current application of the existing legal framework on access to information and public participation in the decision making process. This initiative should be accompanied by an extensive hearing of NGOs, local administrations and other stakeholders in the process.

[54] Council Resolution of 19 December 1994 on radioactive waste management, Resolution of the Committee of the Regions on 'Nuclear Safety and Local/Regional Democracy" of 14 May 1998, and the Parliamentary Resolution on the Safety of transport of nuclear fuel and waste of 18 June 1998, are examples among others.

Annexes

ANNEX 1 Excerpts from Petition 393/95

Note: *The following is a short summary of Petition 393/95 submitted by the Petitioner to the Committee of Petitions of the European Parliament. A longer English summary of the Petition and other documents in German subsequently transmitted by the Petitioner to the Committee of Petitions were done by Mycle Schneider in order to allow the STOA Study Team to better understand the background of the original STOA study request.*

Letter to the President of the European Parliament (EP), dated 22 may 1995

In his letter Dr. Nachtwey stated that he is acting on behalf of 22 senior citizens of Hamburg who are all signatories of the petition to the EP. *"We are asking the EP to prevent any further nuclear pollution of the oceans."* Today the question is whether the oceans will be available as a food source in future given all the chemical and radioactive pollution.

[The petitioner later added references and comments that are noted where particularly relevant.]

Until the beginning of 1995, 7 million litres of radioactive discharges per day.[55] Certainly the cheapest way to discharge the radioactive waste. *"But what will this procedure cost our grand-children and grand-grand-children?"*

The second reprocessing plant will significantly increase the pollution of the environment. In December 1993 THORP got the license to discharge 16.78 million Curies.[56] In 1991 the discharge was 1.25 million Curies. The release to the Irish Sea will increase by 900%. There is no doubt about the fact that the Cumbrian Coast is already highly charged with contaminants. The universities of Bremen and Manchester had in 1992 the possibilities to examine soil samples.[57] In Manchester concentrations up to 13,000 Bq Ce-137 and up to 27,000 Bq of Am-241 [supposedly, in each case, per kg of soil] and up to 10,800 Bq of plutonium were measured. Families come for a picnic, kids play here. Plutonium has been found in plants, animals and houses. The consequences will only be visible in their full scale over the next decades or centuries, some only in thousands of years. A terrible thought if one thinks that already now the childhood leukaemia around Sellafield is ten times the Great Britain average.[58]

Of course, the contamination problem is not confined to the UK and Ireland, but has been identified in Iceland, Norway and Denmark.

The operation of Sellafield and THORP renders PARCOM signed in 1974, ridiculous.

The extent of the pollution through Sellafield and the caused damage is well known. The British government has met ecological and moral concern with grand carelessness.

The Sellafield plant is not the only one. But the French government is less careless: information about radioactive discharges and the degree of coastal pollution are much more difficult to obtain than in the case of Sellafield. We ask the EP to bring about transparency in this respect. The citizens of France and neighbouring countries have a right to this. The French government would do well to commission independent universities with unlimited and uncensored measurements.

The object of our petition is under the responsibility of the EU. The problems, environmental harm and dangers linked to the issue have transboundary character and therefore they can only be met in the framework of the federation of European States.

[55] In the meantime that rose to 9 million litres daily, BNFL Monthly Effluent Reports, January 2000

[56] HMIP, Draft Authorisation for the Disposal of Liquid and Gaseous Radioactive Wastes from Sellafield, November 1992.

[57] University Bremen, Fachbereich Physik/Elektrotechnik, 10 June 1992; University of Manchester, Department of Chemistry, 11 August 1992

[58] Black 1984

ANNEX 2 International Conventions

(a) Main Conventions and Protocols Applying to the Use o f Nuclear Energy

- Vienna Convention on Civil Liability for Nuclear Damage (21 May 1963);
- Optional Protocol Concerning the Compulsory Settlement of Disputes to the Vienna Convention on Civil Liability for Nuclear Damage (21 May 1963);
- Convention on Physical Protection of Nuclear Material (26 October 1979);
- Convention on Early Notification of a Nuclear Accident (26 September 1986);
- Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention (21 September 1988);
- Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (26 September 1986);
- Convention on Nuclear Safety (17 June 1994);
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (1997);
- Convention on Supplementary Compensation for Nuclear Damage (12 September 1997).

(b) Other Relevant Conventions and Documents

- Earth Summit's Agenda for Change - Agenda 21 (June 1992);
- Earth Charter (March 2000);
- IAEA Code of Practice on International Transboundary Movement of Radioactive Waste (1990);
- Convention for the Protection of the Marine Environment of the North-East Atlantic – OSPAR Convention (22 September 1992);
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters (29 December 1972);
- Vienna Convention on Civil Liability for Nuclear Damage (21 May 1963);
- Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (25 June 1998);
- The United Nations Convention on the Law of the Sea (10 December 1982).

ANNEX 3 OSPAR Convention

The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, to which the European Commission is a Contracting Party, is relevant to the deliberations of the Committee on Petitions on nuclide discharges from Sellafield and La Hague. In recent years, the OSPAR Commission has made a number of strongly worded recommendations on the continuing radioactive contamination of European seas and waters by Sellafield and La Hague activities.

The OSPAR Convention came into force on 25 March 1998. The Convention established the OSPAR Commission, an international secretariat based in London, to administer the Convention and to develop policy and international agreements in this field. The Commission is essentially a merger of the former Oslo and Paris Commissions. The Commission has declared its commitment to the application of the precautionary principle, the polluter-pays principle, and to the application of best available techniques (BAT) and best environmental practice (BEP), including, where appropriate, clean technology.

At the Sintra Ministerial Meeting on 22-23 July 1998, Ministers attending OSPAR agreed

> *"to prevent pollution of the marine area by continuously reducing discharges, emissions and losses of hazardous substances (that is, substances which are toxic, persistent and liable to bioaccumulate or which give rise to an equivalent level of concern), with the ultimate aim of achieving concentrations in the environment near background values for naturally occurring substances and close to zero for man-made synthetic substances. We shall make every endeavour to move towards the target of cessation of discharges, emissions and losses of hazardous substances by the year 2020. We emphasise the importance of the precautionary principle in this work."*

Specifically on radioactive substances, Ministers further agreed

> *"to prevent pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. In achieving this objective, the following issues should, inter alia, be taken into account:*
>
> - *legitimate uses of the sea;*
> - *technical feasibility;*
> - *radiological impacts to man and biota.*
>
> *We shall ensure that discharges, emissions and losses of radioactive substances are reduced by the year 2020 to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero (see paragraph 15)".*

These commitments are more onerous than appear at first sight. Ministers have committed themselves to achieving concentrations ***in the environment*** close to zero; not concentrations ***in discharges***. Nuclide concentrations in the environments at Sellafield and La Hague are already high. For example, critical group doses from previous discharges at Sellafield account for about 75% of total annual dose: only 25% of dose comes from present annual discharges. In other words, in order to achieve such reductions, present discharges at Sellafield and La Hague would have to be severely curtailed. Furthermore the phrase *"progressive and substantial reductions"* appears to indicate that decisions leading to increases, even if temporary, would not be in accord with Ministers' commitments. It is noted that four documents from the Sintra meeting need to be considered when evaluating the implications for radioactive substances These are: the Sintra Statement; the OSPAR Strategy with regard to Radioactive Substances; the OSPAR Action Plan 1998-2003, and the 1998-1999 Work Programme for the OSPAR Working Group on Radioactive Substances.

However since 1998, progress has been limited. Both Sellafield and La Hague have issued proposals to increase radioactive discharges, which have been looked upon with favour by the Governments involved. In November 1999, the UK Government approved a new variation to Sellafield's discharge authorisations, which allowed aerial emissions of some nuclides to increase. In France, COGEMA in 2000 issued

proposals [1998, 2000] for increased reprocessing throughputs at La Hague which would result in significant increases in specified nuclide discharges, without apparent opposition from the French Government.

In June 2000, at the Annual Meeting of the OSPAR Commission in Copenhagen, the UK submitted proposals for significant increases in alpha and beta discharges from Sellafield and Dounreay. At this meeting, Decision 2000/1 was agreed by all Contracting Parties, apart from the abstentions of UK, France and the EC. Luxembourg was not present but agreed to the Decision later. Decision 2000/1 states that:

> *"The current authorisations for discharges or releases of radioactive substances from nuclear reprocessing facilities shall be reviewed as a matter of priority by their competent national authorities, with a view to, inter alia: implementing the non-reprocessing option (for example dry storage) for spent nuclear fuel management at appropriate facilities."*

The Summary Record shows that the UK and France abstained as they took the view that the Decision was outside OSPAR's remit. (Reported from Summary Record, Meeting of the OSPAR Commission, Copenhagen, 26-30 June, OSPAR 00/20/1-E). As a result of their abstentions, it is understood the UK and France do not consider Decision 2000/1 binding on themselves.

It is also understood that the EC may not take a position (i.e. vote) when Member States are divided. However, in October 2000, Margot Wallstrom, European Environment Commissioner stated

> *"there is now broad support for the implementation of the non-reprocessing option."* [59]

She added that the Commission would continue to contribute to allow the strategy on radioactive substances to be implemented and progress to be assessed. In addition, the European Commission would give its full support to requiring OSPAR Contracting Parties to implement the Strategy adopted at Sintra.

A study by the Nuclear Energy Agency of the OECD was presented at the Copenhagen meeting. OSPAR Decision 2000/1 noted the study demonstrated that implementing the non-reprocessing option (dry storage) for spent fuel would eliminate the discharges and emissions of radioactive substances that currently arise from reprocessing it.

[59] Margot Wallström, Letter to Greenpeace International, 17 October 2000.

ANNEX 4 European Legislation, Regulation and Policy Statements

(a) European Treaties

- Treaty establishing the European Community, signed in Rome and entered into force on 1 January 1958;
- Treaty establishing the European Atomic Energy Community (Euratom), signed in Rome and entered into force on 1 January 1958;
- The Single European Act (SEA), signed in Luxembourg and The Hague and entered into force on 1 July 1987;
- Treaty on European Union, signed in Maastricht and entered into force on 1 November 1993;
- Treaty of Amsterdam, which entered into force on 1 May 1999.

(b) European Commission Regulations, Recommendations, Opinions

• Regulations

- Commission Regulation (Euratom) No 3227/76 of 19 October 1976 concerning the application of the provisions on Euratom safeguards;
- Commission Regulation (Euratom) No 3227/76 of 19 October 1976 concerning the application of the provisions on Euratom safeguards.

• Recommendations

- Commission Recommendation 82/74/Euratom of 3 February 1982 on the storage and reprocessing of irradiated nuclear fuels;
- Commission Recommendation 1999/829/Euratom of 6 December 1999 on the application of Article 37 of the Euratom Treaty;
- Commission Recommendation 00/473/Euratom of 8 June 2000 on the application of Article 36 of the Euratom Treaty concerning the monitoring of the levels of radioactivity in the environment for the purpose of assessing the exposure of the population as a whole.

• Opinions

- Commission Opinion 89/475/Euratom of 20 July 1989 concerning the nuclear fuel reprocessing plants UP3 and UP2800 of the La Hague Establishment (France);
- Commission opinion of 5 October 2000 concerning the plan for the disposal of radioactive waste from the 'Centre de la Manche' radioactive waste storage facility located in the region of Lower Normandy (France), in accordance with Article 37 of the Euratom Treaty.

(c) Council of the European Union Directives and Regulations

• Directives

- Council Directive of 15 July 1980 amending the Directives laying down the basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation 80/836/Euratom;
- Council Directive of 3 September 1984 amending Directive 80/836/Euratom as regards the basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation 84/467/Euratom;
- Council Directive 92/3/Euratom of 3 February 1992 on the supervision and control of shipments of radioactive waste between Members States and into and out of the Community;
- Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation.

• Regulations

- Council Regulation (Euratom) 1493/93 of 8 June 1993 on shipments of radioactive substances between Member States;
- Commission Regulation (Euratom) No 2130/93 of 27 July 1993 amending Regulation (Euratom) No 3227/76 concerning the application of the provisions on Euratom safeguards Council Regulation (Euratom) No 1493/93 of 8 June 1993 on shipments of radioactive substances between Member States;
- Council Resolution of 19 December 1994 on radioactive-waste management.

(d) European Parliament Resolutions

- Resolution on nuclear waste and pollution at sea of 16 November 1995;
- Resolution on radioactive waste 27 March 1996;
- Resolution on the safety of transport of nuclear fuel and waste of 18 June 1998;
- Resolution on the safe transport of radioactive material of 13 March 2001.

ANNEX 5 The Precautionary Principle: Not Using the Sea as an Experimental Laboratory

In the recent years, suggestions have been made that the environment may be treated akin to a large experimental laboratory. For example, a MAFF Report [Kershaw et al, 1992] stated that:

> *"...the likely increased discharge of technetium-99 from Sellafield...from 1993 onwards will provide an opportunity to use this tracer to study water movements, and validate transfer models, within the Irish Sea, and exchange in the North Channel, Malin Shelf and along the Scottish coastal current."*

A similarity exists between this statement and that made by John Dunster in 1958 to a UN Conference on the Peaceful Uses of Atomic Energy on "The Environmental Aspects of the Large Scale Use of Atomic Energy":

> *"In general terms the intention has been to discharge fairly substantial amounts of radioactivity as part of an organised and deliberate scientific experiment and the aims of this experiment would in fact have been defeated if the level of activity had been kept to a minimum."*

And, from more recent publications:

> *"^{99}Tc… which is less susceptible to removal from the water column and has effectively no history because of the stepped nature of the discharge, offers a better tool to study the movement of effluent within and from the Irish Sea."* [Leonard *et al*, 1997]

And also

> *"The increase in discharges has resulted in increased concentrations in certain environmental media found in the Irish Sea, providing an ideal opportunity for further study."* [Busby *et al*, 1997]

Given the uncertainties described in the present report, it is clearly contrary to the Precautionary Principle to continue to discharge radionuclides such as technetium-99 at high levels, treating the marine environment both as convenient sink and interesting laboratory.

In addition, important information about the behaviour of technetium-99 is not in fact being obtained: for example, the beaches and tidewashed pastures of the Solway Firth (in South West Scotland) are regularly inundated with seawater containing nuclides from Sellafield effluent, and are grazed by sheep and cattle. Apart from limited FSA monitoring of shellfish and seaweed, there has been no effort as yet to obtain additional information about the environmental behaviour of technetium-99 in this area, despite the fact that *"saltmarshes are important ecological areas, and may facilitate the transfer of radionuclides from the marine environment to terrestrial foodchains."* [Nicholson *et al*, 1992]

A more responsible approach would be to apply the Precautionary Principle, and to defer such technetium discharges while important uncertainties about its behaviour remain. BNFL claims [see accompanying evidence to Environment Agency, 2000] that the costs of technetium-99 removal are *"grossly disproportionate"* to the detrimental cost of the dose (to the critical group) from technetium-99 at the proposed limit. Even if it were accepted that radiological detriment could be offset against financial gain, such an assertion assumes a high degree of confidence in estimates of detriment. This confidence is not warranted by the uncertainties described above.

ANNEX 6 Background Information on Collective Dose

Collective dose is a measure of the exposure of a population over time from a given release of radionuclides and is an indicator of total detriment to health from the resulting radiation. The ICRP [1991] has stated that collective dose represents the total consequences of an exposure of a population or group, and has defined collective effective dose, S, as

$$S = \sum \bar{E}_i (N_i)$$

where E_i is mean effective dose to population subgroup i and N_i is the number of individuals in subgroup i. In other words, collective dose is the product of the average dose to a population times the size of the population. The concept of collective dose has been described by Fairlie and Sumner [2000] and Barraclough *et al* [1996].

(a) Official Use of Collective Dose

The use of collective dose by international agencies and national regulatory bodies has a lengthy pedigree [see discussion in NCRP 1995]. For example, in 1965, the Canadian Atomic Energy Control Board introduced an annual population dose limit of 100 person Sv per nuclear power station. In 1985, Sweden introduced a *"reference level"* for the management of releases from Swedish nuclear reactors of 5 person Sv per GW year of electricity generating capacity [Snihs, 1996].

International and national agencies routinely estimate collective doses, including UNSCEAR [UNSCEAR, 1983; 1988; 1993; 2000]; the Canadian Environmental Assessment Agency [CEAA, 1995]; the IAEA [1985]; and the UK NRPB [Lawson *et al*, 1990; Mayall *et al*, 1993]. The UK NRPB's dose model (PC CREAM) for estimating doses from nuclide releases estimates both collective and individual doses.

Euratom Directive 96/29 on Basic Safety Standards in Radiation Protection stipulates that Member States should have introduced national legislation (by May 2000) requiring their national agencies on radiation protection to fulfil procedural requirements on radiation protection. In particular, the Directive contains numerous provisions requiring national agencies to calculate and use population (i.e. collective) doses. These include (in the order listed in the Directive):

i. Article 14 on optimisation of population doses.

ii. The whole of Title VIII on radiation protection for the population.

iii. The whole of Title IX on lasting exposures.

iv. Article 45 on calculation of collective doses as a condition of authorisations and licensing of radioactive discharges

v. Annex I on exemption provisions that use collective dose as the criterion for exemption.

(b) Estimation of Collective Doses

To estimate collective doses, the ***population*** and the ***truncation*** period, if any, must be defined. Populations whose doses are calculated may consist of the workforce, the people in the immediate locality, the relevant country, Europe, and the world. Methods for estimating such doses are described in the various reports cited above.

As regards truncation periods, the UK NRPB estimates two types: truncation after 500 years and no truncation. UNSCEAR routinely uses a truncation period of 10,000 years in its reports. Few, if any, rules exist on which period should be used. The UK NRPB's view is that, as there are uncertainties over events in the long-term future (for example, a cancer cure could be found) both sets of doses are estimated.

Fairlie and Sumner [2000] have raised ethical and practical points against truncation. Ethically speaking, truncation at 500 years negates detriment to generations after 500 years, which runs counter to the principle of sustainable development and the IAEA's Radioactive Waste Management Principles [1995]. In practical terms, truncation after 500 years is unsound in the case of very long-lived nuclides such as iodine-129 or technetium-99, as it would ignore almost all (>99%) detriment. [see IAEA, 1995]

(c) Uncertainties

Inevitably, uncertainties remain about the existence, sizes and habits of populations, climate, and the environment for long periods into the future. For example it is expected that another ice age will peak in the northern hemisphere in approximately 10,000 years and that repeated glacial cycling will occur thereafter [NRPB, 1992].

However the use of uncertainty as a reason for avoiding the use of collective dose does not appear to satisfy the Precautionary Principle, which states, *inter alia*, that lack of scientific certainty should not be employed as a reason for deferring measures to enhance the quality of the environment [Hey, 1995]. The precautionary principle is one of the supporting principles underpinning the policy of sustainable development formally accepted by the European Commission at the 1992 UN Conference on Environment and Development.

In addition, similar large uncertainties in other parameters used in radiation protection do not prevent their use. For example, large uncertainties exist in the assessment of terrestrial foodchain doses [Smith *et al* 1998], and in estimates of individual doses to members of critical groups from projected radioactive waste repositories arising 10^4 to 10^6 years in the future [Neall *et al*, 1994]. Of course, these uncertainties are acknowledged, but they do not prevent publication and peer discussion, nor their usefulness for heuristic [McCombie *et al*, 1991; NAGRA, 1994] or for decision-taking [AECL, 1994] purposes. Estimates of collective dose should be treated similarly.

(d) Comparisons with Background Radiation

Collective doses are received from background levels of radiation (on average – there are large variations from one area to the other – about 2.4 mSv per person per year in the UK and France) and some commentators compare collective doses from discharges with background doses, in attempts to put them *"into context"* [see, for example, RWMAC, 1993; Clarke, 1994; Coulston, 1994; BNFL, 1998]. Such comparisons run the risk of inviting the lay reader to infer that anthropogenic collective doses, and the practices which caused them, are therefore acceptable.

A number of objections can be made against such comparisons. First, comparisons with natural background doses infer that background radiation may be viewed with equanimity. This is not quite the case, of course. The NRPB has estimated that natural background radiation results in about 6,000 to 7,000 UK cancer deaths per year in the UK [Robb, 1994]. The application of the collective dose and the ICRP risk factor to the French population leads to a similar figure for France.

Second, a number of authors have stated that comparisons of radiation exposures from anthropogenic releases with natural background radiation levels are inappropriate. See comments by Lindell [1989], NRPB [1990], Webb *et al* [1983] and in European Commission documents, for example chapter 8.3.4 in Bush *et al* [1984]. Comparisons with background radiation of course conflate different, i.e. naturally-occurring and anthropogenic, risks. Risks from anthropogenic releases are subject to social and political processes as the Committee's hearing attests: background radiation risks are not.

Third, comparisons with background exposures are not used to justify the acceptability of industrial discharges of naturally occurring chemical toxins, e.g. carbon monoxide, ozone, dioxins or furans.

Finally, the ICRP system of radiation protection of limitation, optimisation and justification [ICRP, 1991] notably refrains from using background radiation as a criterion of radiological acceptance.

ANNEX 7 Individual Exposures from Consumption of Seafood around Sellafield

Table 14 Individual Radiation Exposures from Consumption of Irish Sea Fish and Shellfish

Exposed population (1)	Foodstuffs	Exposure (mSv/a) ^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{137}Cs
Sellafield fishing community	plaice, cod, crabs, lobsters, winkles	0.005	0.002	0.005	0.016	0.003	0.009
Whitehaven commercial fisheries	plaice, cod, *Nephrops*, whelks	0.002			0.002		0.005
Dumfries Galloway	plaice, cod, salmon, crabs, lobster, *Nephrops*, winkles mussels	0.002			0.005		0.005
Morecambe Bay	flounders, plaice, shrimps, cockles, mussels	0.003			0.002		0.012
Fleetwood	plaice cod shrimps whelks	0.002					0.010
Isle of Man	fish, shellfish				0.003		0.003
Northern Ireland	fish, shellfish				0.002		0.005
North Wales	fish, shellfish						0.002
Member of public(5)	plaice, cod						0.001

	(continued)	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Other(6)	Ext	Total
Sellafield fishing community	plaice, cod, crabs, lobsters, winkles	0.008	0.046	0.010	0.082	<0.002	0.023	**0.2l**(4)
Whitehaven commercial fisheries	plaice, cod, *Nephrops*, whelks	0.002	0.009	0.002	0.015	<0.002	0.009	**0.038**
Dumfries Galloway	plaice, cod, salmon, crabs, lobster, *Nephrops*, winkles mussels		0.002	0.005	<0.001			**0.028**(2)
Morecambe Bay	flounders, plaice, shrimps, cockles, mussels	0.002	0.012	0.003	0.023	<0.001	0.013	**0.071**(3)
Fleetwood	plaice cod shrimps whelks		0.003		0.004	<0.002		**0.021**
Isle of Man	fish, shellfish					<0.004		**0.010**
Northern Ireland	fish, shellfish				0.003	<0.003		**0.013**
North Wales	fish, shellfish				0.002	<0.002		**0.006**
Member of public(5)	plaice, cod					<0.001		**0.002**

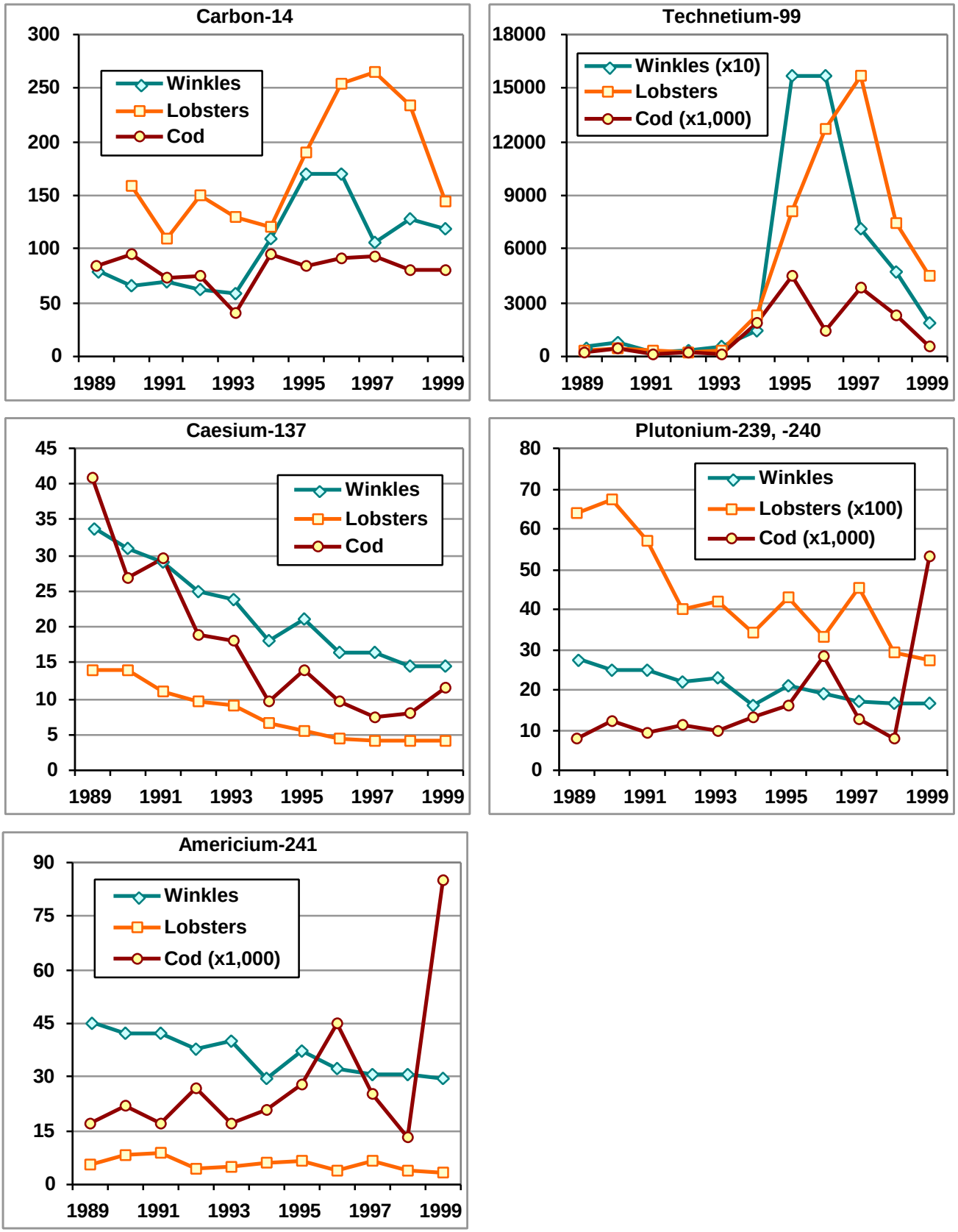
Blank data indicate a dose of less than 1 µSv.

(1) Representative of people most exposed unless stated otherwise
(2) Including exposure due to 1000 h/year occupancy over intertidal sediments
(3) Including exposure due to 900 h/year occupancy over intertidal sediments
(4) Including exposure due to 1000 h/year occupancy over intertidal sediment
(5) "Other" comprises data for all radionuclides with doses below 1 µSv.
(6) Member of public consuming fish landed at Whitehaven and Fleetwood

Source: [FSA, 2000]

ANNEX 8 Concentration of Radionuclides in Seafoods from Sellafield

Figure 14 Concentrations in Cod, L obsters and Winkles from Sellafield in Bq/kg (wet)



The high americium-241 reading in cod in 1999 was stated in the FSA report as being "anomalous"

Source: [FSA, 2000]

ANNEX 9a Environmental Concentrations of Nuclide Discharges from Sellafield

In the following tables,

- * means that the nuclide was undetected using that particular method of detection,
- a blank entry means no sample was measured.
- < means that the concentration found was below the Lower Limit of Detection (LLD). To be more precise, taking into account counting time, chemical yield, and decay since collection, the nuclide concentration was lower than the value indicated.
- "No." means the number of samples measured.
- Figures in bold brown signify concentrations above relevant CFILs (European Community Food Intervention Levels).

Table 15a Fish: Beta/gamma Radioactivity in Fish from the Irish Sea Vicinity in 1999 (ranked by ^{137}Cs concentration)

			Mean radioactivity concentration (wet), Bq/kg										
Location	**Material**	**No.**	**^{3}H**	**^{14}C**	**^{60}Co**	**^{90}Sr**	**^{95}Zr**	**^{95}Nb**	**^{99}Tc**	**^{106}Ru**	**^{134}Cs**	**^{137}Cs**	**Total beta**
Morecambe (Flookburgh)	Flounder	4		77	<0.09		<0.25	<0.28		<0.85	<0.09	17	
Sellafield coastal area	Cod	5			0.67		<0.31	<0.57		<0.77	<0.16	14	160
Sellafield coastal area	Bass	1			<0.16		<0.61	<0.80		<1.6	<0.17	13	
Sellafield coastal area	Grey mullet	1			<0.12		<0.27	<0.28		<0.97	<0.10	12	
Sellafield offshore area	Cod	1		85	<0.12	0.036	<0.24	<0.23	0.72	<0.86	<0.10	12	
Sellafield offshore area	Whiting	2			<0.08		<0.21	<0.24		<0.62	<0.07	12	
Parton	Cod	4			<0.12		<0.20	<0.22		<0.68	<0.08	12	
Whitehaven	Cod	4		75	<0.20	0.037	<0.16	<0.13		<0.75	<0.09	11	
Ravenglass	Cod	4			0.33		<0.26	<0.38		<0.69	<0.08	10	150
Sellafield offshore area	Spurdog	2			<0.09		<0.26	<0.37		<0.73	<0.07	9.5	
Sellafield coastal area	Plaice	4	230		0.34		<0.31	<0.47		<0.76	<0.08	8.0	150

Source: [FSA, 2000]

Table 15b Fish: Beta/gamma Radioactivity in Fish in Distant Ar ea in 1999 (ranked by ^{134}Cs concentration)

			Mean radioactivity concentration (wet), Bq/kg								
Location	**Material**	**No.**	**^{14}C**	**^{60}Co**	**^{90}Sr**	**^{95}Zr**	**^{95}Nb**	**^{99}Tc**	**^{106}Ru**	**^{134}Cs**	**Total beta**
Baltic Sea	Cod	2		<0.06		<0.32	<0.58	<0.61	0.17	13	
Baltic Sea	Herring	2		<0.08		<0.44	<0.82	<0.78	<0.09	8.9	
Skagerrak	Herring	4		<0.07		<0.24	<0.31	<0.67	<0.07	0.66	
Skagerrak	Cod	4		<0.05		<0.22	<0.44	<0.43	<0.05	0.42	
Celtic Sea	Cod	4	19	<0.05	<0.024	<0.13	<0.14	<0.42	<0.05	0.40	
Celtic Sea	Plaice	4		<0.08		<0.23	<0.24	<0.74	<0.08	0.30	
Barents Sea	Cod	4		<0.07		<0.52	<0.23	<0.67	<0.07	0.29	
Iceland area	Cod	1		<0.06		<0.22	<0.28	<0.54	<0.06	0.19	
Icelandic processed	Cod	2	20	<0.04		<0.07	<0.05	<0.31	<0.04	0.19	

Source: [FSA, 2000]

Table 16 Shellfish: Beta/gamma Radioactivity in Shellfish from Irish Sea Vicinity in 1999 (ranked by ^{99}Tc concentration)

			Mean radioactivity concentration (wet), Bq/kg								
Location	**Material**	**No.**	**^{3}H**	**^{14}C**	**^{60}Co**	**^{90}Sr**	**^{95}Zr**	**^{95}Nb**	**^{99}Tc**	**^{106}Ru**	**^{110m}Ag**
Sellafield coast area	Lobsters	8		150	3.9	0.70	<0.48	<0.84	**4,700**	<1.4	4.4
Ravenglass	Lobsters	4			2.8	0.31	<0.42	<0.96	**4,400**	<0.94	4.4
Sellafield coast area	*Nephrops*	1			0.77		<0.52	<0.66	990	<1.6	<0.30
Sellafield coast area	Limpets	4		58	6.2	6.1	<0.17	<0.17	990	9.9	4.8
Ravenglass	Mussels	4	92		8.4		<0.18	<0.13	920	12	<0.18
Sellafield coast area	Winkles	4		110	25	4.7	<0.54	<0.56	290	19	9.1
Sellafield coast area	Winkles	4		110	25	4.7	<0.54	<0.56	290	19	9.1
Sellafield coast area	Whelks	2		98	3.4	0.15	<0.30	<0.56	120	2.3	2.4
Ravenglass	Cockles	4		140	36	2.5	<0.23	<0.16	58	14	<0.32
Sellafield coast area	Crabs	8		120	4.4	1.6	<0.40	<0.69	53	<1.2	<2.4
Sellafield coast area	Mussels	4			14	2.0	<0.25	<0.20		20	<0.22
Sellafield offshore area	Whelks	2			4.1		<0.22	<0.24		6.2	3.6
Ravenglass	Winkles	2			12		<0.22	<0.21		11	7.5

Source: [FSA, 2000]

Table 17 Fish and Shellfish: Transuranic Radioactivity in Fish and Shellfish from Irish Sea Vicinity in 1999 (ranked by ^{239}Pu + ^{240}Pu concentration)

			Mean radioactivity concentration (wet), Bq/kg						
Location	**Material**	**No.**	**^{237}Np**	**^{238}Pu**	**^{239}Pu+^{240}Pu**	**^{241}Pu**	**^{241}Am**	**^{242}Cm**	**^{244}Cm**
Nethertown	Winkles	4	0.037	3.4	17	**190**	**30**	*	0.057
St Bees	Winkles	1	0.027	2.6	14	**150**	**26**	0.081	0.047
Drigg	Winkles	4	0.034	2.7	13	**150**	**30**	<0.018	<0.047
Tarn Bay	Winkles	1		2.6	13	**140**	**23**	*	0.070
Ravenglass	Cockles	1		2.3	12	**130**	**33**	*	0.048
Sellafield coastal area	Winkles	1	0.027	2.3	11	**120**	12	*	0.024
Sellafield coastal area	Limpets	1		2.3	11	**130**	**20**	*	0.037
St Bees	Limpets	1		2.0	10		**20**	0.043	0.037
Sellafield coastal area	Mussels	1		2.0	9.8	**120**	19	*	0.045
Nethertown	Mussels	4		1.9	9.1		17	<0.018	0.046
St Bees	Mussels	2		1.7	8.3	**96**	**27**	*	0.075
Ravenglass	Mussels	1		1.2	5.8	**68**	13	*	0.021
Sellafield offshore	Whelks	1		0.51	2.6	**29**	5.7	*	0.011
Sellafield coastal area	Whelks	1		0.35	1.7	19	4.3	*	0.0070
Sellafield coastal area	*Nephrops*	1		0.083	0.43		2.7	0.0022	0.0031
Sellafield coastal area	Crabs	2	0.0044	0.070	0.34	4.0	1.6	<0.0030	0.0036
Sellafield coastal area	Lobsters	2	0.02 1	0.059	0.28	3.1	3.8	*	0.0088
Ravenglass	Crabs	1		0.052	0.26	3.1	1.5	0.0014	0.0032
Ravenglass	Lobsters	1		0.054	0.25	2.7	3.1	*	0.0088
Sellafield coastal area	Plaice	1		0.003 8	0.024		0.032	0.000089	0.000049
Ravenglass	Plaice	1		0.0017	0.0082		0.014	*	0.000023
Sellafield coastal area	Cod	2		0.00090	0.0044		0.0073	<0.00022	<0.000073
Ravenglass	Cod	1		0.00068	0.0035		0.0039	*	0.000011
Saltom Bay	Winkles	4					18		

Source: [FSA, 2000]

Table 18a Sediments: Radioactivity in Sediment from the Cumbrian Coast and further Afield in 1999 (ranked by ^{137}Cs concentration)

			Mean radioactivity concentration (dry), Bq/kg								
Location	**Material**	**No.**	**^{60}Co**	**^{95}Zr**	**^{95}Nb**	**^{106}Ru**	**^{125}Sb**	**^{134}Cs**	**^{137}Cs**	**^{144}Ce**	**^{154}Eu**
Cumbria											
Newton Arlosh	Turf		2.5	<2.4	<3.2	<8.2	<3.2	<0.80	630	<4.3	<2.8
Ravenglass - Carleton Marsh	Mud		49	<2.6	*<2.5*	110	*<6.5*	<1.0	540	15	13
Newbiggin	Mud		52	<2.8	<3.1	87	<6.1	<1.0	360	<12	8.9
Ravenglass - Raven Villa	Mud, sand		43	<2.6	<2.7	73	<5.2	<1.0	270	9.7	7.0
Millom	Mud, sand		11	<1,8	<1.7	<21	<2.3	<0.72	250	<4.4	4.4
SandGatemarsh	Turf		1.2	<1.4	*<1.5*	<5.3	<1.9	<0.58	240	<2.9	<1.7
Flookburgh	Mud, sand		<1.5	<1.1	<1.2	<4.1	<1.3	<0.48	100	*<2.5*	<1.2
StBees	Sand		4.0	<0.88	<0.91	<3.3	<1.0	<0.34	85	<1.9	*1.5*
Sellafield	Sand		4.9	<0.97	<0.95	<3.7	<1.2	<0.39	84	<2.1	1.9
South-west Scotland											
Kippford Merse	Salt marsh	4	5.3	<0.40	<0.29	<10	2.2	0.25	750	<1.0	*5.8*
Kippford Slipway	Mud	4	4.2	<0.36	<0.23	7.1	<1.3	<0.30	270	<1.3	2.2
Palnackie Harbour	Mud	4	4.9	<0.34	*<0.25*	14	<1.0	<0.17	230	<0.97	2.3
Carsluith	Mud	4	2.9	<0.36	<0.29	8.9	<0.91	<0.18	200	<1.1	2.2
Innerwell	Mud	6	<2.0	<0.69	<0.65	<3.4	<0.91	<0.31	120	<1.7	<1.0
Carsethorn	Mud, sand	2	0.49	<0.77	<0.13	<0.91	<0.37	<0.12	110	<0.67	<0.35
Garlieston	Mud	4	1.0	*<0.25*	<0.20	<1.1	<0.41	<0.12	65	<0.78	<0.36
Northern Ireland											
Carlingford Laugh	Mud	2	<0.49	<2.1	<3.0	<5.3	<1.6	<0.70	85	<3.1	<1.6
Oldmill Bay	Mud	2	<0.44	<2.0	<3.9	<4.3	<1.2	*<0.53*	68	<2.1	<1.3
Ballymacormick	Mud	2	<0.38	<1.6	<2.2	<3.9	<1.0	<0.48	37	<2.1	<1.1
Strangford Laugh Nickeys point	Mud	2	<0.19	<0.76	<1.0	<2.0	<0.57	*<0.25*	32	<1.4	<0.56
Dundrum Bay	Mud	2	<0.24	<0.89	<1.1	<2.5	<0.63	<0.32	9.3	<1.6	<0.79
LoughFoyle	Mud, sand	2	<0.22	<0.95	<1.3	<2.6	<0.74	<0.31	*2.5*	<2.1	<0.69
Portrush	Sand	2	<0.18	<0.93	<1.4	<2.1	<0.49	<0.24	1.2	<1.1	<0.58

Source: [FSA, 2000]

Table 18b Sediments: Radioactivity in Se diment from the Cumbrian Coast and further Afield in 1999 (ranked by ^{241}Am concentration)

			Mean radioactivity concentration (dry), Bq/kg						
Location	**Material**	**No.**	**^{155}Eu**	**^{238}Pu**	**^{239}Pu+^{240}Pu**	**^{241}Pu**	**^{241}Am**	**^{242}Cm+^{244}Cm**	**Total beta**
Cumbria									
Ravenglass – Carleton Marsh	Mud	4	6.6				1100		
Newbiggin	Mud	4	<4.8	110	520	6100	810	1.8	1500
Ravenglass – Raven Villa	Mud, sand	4	<3.2				550		
Millom	Mud, sand	4	<3.0				350		
Newton Arlosh	Turf	4	<2.5				240		
Sellafield	Sand	4	<1.2				200		
St Bees	Sand	4	<0.90				180		
Sand Gate marsh	Turf	4	<1.3				97		
Flookburgh	Mud, sand	4	<1.3				55		
South-west Scotland									
Kippford Merse	Salt marsh	4	<2.5	60	310		450		
Palnackie Harbour	Mud	4	<1.7	30	160		310		
Carsluith	Mud	4	<1.3	24	120		200		2,100
Kippford Slipway	Mud	4	<1.1	26	130		200		
Carsethorn	Mud, sand	1	<0.7				40		
Garlieston	Mud	4	<0.49	6.1	34	47			
Innerwell	Mud	6	<1.7			77			
Northern Ireland									
Oldmill Bay	Mud	2	<0.94	3.5	19		28	0.066	
Bally-macormick	Mud	2	<0.96	3.0	17		20	0.031	
Carlingford Laugh	Mud	2	<2.4	2.2	13		8.3		
Strangford Laugh - Nickey's point	Mud	2	<0.66	1.2	7.0		7.1	0.021	
Dundrum Bay	Mud	2	<0.79				<1.6		
LoughFoyle	Mud, sand	2	<1.0	0.11	0.56		0.74	0.0031	
Portrush	Sand	2	<0.52				<0.61		

Source: [FSA, 2000]

Table 19 Aquatic Plants: Radioactivity in Aquatic Plants from the Cumbrian Coast and further Afield in 1999 (ranked by ^{99}Tc then ^{106}Ru concentration)

			Mean radioactivity concentration (wet), Bq/kg								
Location	**Material**	**No.**	**^{14}C**	**^{60}Co**	**^{90}Sr**	**^{99}Tc**	**^{106}Ru**	**^{137}Cs**	**^{239}Pu ^{240}Pu**	**^{241}Am**	**Total beta**
England											
Sellafield	*Fucus vesiculosus*	4		51	3.9	**13,000**	<2.4	9.2	12	5.6	10,000
St Bees	*Fucus vesiculosus*	4	50	20	3.2	**9,800**	<1.4	7.5	10	6.1	
StBees	*Porphyra*	4	45	1.7	0.38	8.4	8.9	1.9	2.6	5.9	190
Rabbit Cat How, Ravenglass	Samphire	1		0.26		1.0	<0.43			1.6	
Seascale	*Porphyra*	52		2.8			<13	2.1		5.6	
Braystones south	*Porphyra*	4		1.9			12	1.9	1,5	3,2	
StBees	*Rhody-menia spp.*	2		2.7			5.1	13	3.6	9.6	
Cockerham Marsh	Samphire	1		0.11			<0.25	2.1		1.1	
Marshside Sands	Samphire	1		<0.03			<0.25	0.56		0.3	
Scotland											
Auchencairn	*Fucus vesiculosus*	8		1.8		**2,800**	<0.76	6.6		3.2	
Garlieston	*Fucus vesiculosus*	8		1.3		**1,800**	<0.63	6.7		5.6	
Fort William	*Fucus vesicolosus*	8		<0.35		**1,600**	<0.67	2.2		<0.35	
Cape Wrath	*Ascophyl. nodosum*	2		<0.05		910	<0.46	0.44		<0.17	
Knock Bay	*Porphyra*	8		<0.08			<0.46	0.39		<0.49	
Wick	*Fucus vesiculosus*	1		<0.05			<0.40	0.24		<0.22	
Northern Ireland											
Carlingford Laugh	*Fucus spp.*	2		0.12		700	<0.81	1.7		<0.11	
Ardglass	*Fucus vesiculosus*	4		<0.10		500	<0.66	1.0		<0.22	
StrangfordLough	*Rhodymeni aspp.*	2		<0.12		66	<1.1	0.99		0.41	
Portrush	*Fucus serratus*	4		<0.06			<0.47	0.16		<0.16	

Source: [FSA, 2000]

ANNEX 9b Environmental Concentrations of Nuclide Discharges from La Hague

Table 20 Radionuclide concentration in fish from the La Hague area in 1996/1997 (in Bq/kg)

Sampling area	Material	Measured by	^{60}Co		^{106}Ru/^{106}Rh	
			Average	Maximum	Average	Maximum
West Coast (1997)	Round fish	COGEMA	<0.08	0.16	<1.07	<1.80
West Coast (1997)	Flat fish	COGEMA	<0.88	<1.10	<0.06	<0.09
North Coast (1997)	Round fish	COGEMA	<0.82	<1.40	<0.88	<1.60
North Coast (1997)	Flat fish	COGEMA	<0.06	0.09	<0.06	<0.11
Les Huquets (1996)	Gadus luscus	GEA	0.38	0.38	-	-
Flamanville (1996)	Labrus bergylta	GEA	<0.41	0.58	<3.23	1.66
Cap Lévy (1996)	Gadus luscus	GEA	<0.23	0.28	-	-
Fermanville-Cap Lévy (1996)	Labrus bergylta	GEA	<0.19	0.17	-	-
Flamanville (1997)	Labrus bergylta	EDF	0.13	0.13	-	-

Source: [GRNC, GT-2, 1999]

Table 21 Radionuclide concentration in limpets from the La Hague area in 1996/1997 (in Bq/kg)

Sampling area	Material	Measured by	^{60}Co		^{106}Ru/^{106}Rh	
			Average	Maximum	Average	Maximum
Querqueville (1996)	Limpets	GEA	0.45	0.57	<2.11	2.48
Anse St Martin (1996)	Limpets	GEA	0.69	1.49	<2.68	3.65
Dielette (1996)	Limpets	LERFA	0.4	1	-	-
Carteret (1996)	Limpets	LERFA	0.37	0.62	-	-
Goury (1996)	Limpets	GEA	0.95	1.69	<3	4.7
Moulinets (1997)	Limpets	OPRI	0.34	0.47	<2.6	<2.6
Barneville (1997)	Limpets	OPRI	0.28	0.32	<1.54	<1.9
Anse des Moulinets (1997)	Limpets	COGEMA	0.61	0.79	6	7.6
Querqueville (1997)	Limpets	COGEMA	0.41	0.53	<1.2	1.6
Sciotot (1997)	Limpets	COGEMA	0.78	0.8	6.5	10
Goury (1997)	Limpets	COGEMA	0.43	0.55	3.8	5.3
Ecalgrain (1997)	Limpets	COGEMA	0.69	1.3	5.6	8.5
Urville (1997)	Limpets	COGEMA	0.42	0.55	2	2.8

Source: [GRNC, GT-2, 1999]

Table 22 Radionuclide concentration in mussels from the La Hague a rea in 1996/1997 (in Bq/kg)

Sampling area	Material	Measured by	^{60}Co		^{106}Ru/^{106}Rh	
			Average	Maximum	Average	Maximum
East Coast	Mussels	COGEMA	0.31	0.78	<0.9	<1.2
West Coast	Mussels	COGEMA	0.37	0.67	<0.9	<l. l
East Coast (1997)	Oysters	COGEMA	<0.09	0.12	<0.88	<1.20
St Vaast (1996)	Oysters	GEA	0.13	0.21	-	-
St Vaast (1997)	Oysters	OPRI	<0.67	<0.67	<5.00	<5.00

Source: [GRNC, GT-2, 1999]

Table 23 Radionuclide concentration in shellfish from the La Hague area in 1996/1997 (in Bq/kg)

Sampling area	Material	Measured by	^{60}Co		^{106}Ru/^{106}Rh	
			Average	Maximum	Average	Maximum
West Coast	Shellfish	COGEMA	1.8	1.9	2.1	2.3
North Coast	Shellfish	COGEMA	3.1	4.4	2.82	4.7

Source: [GRNC, GT-2, 1999]

Table 24 Radionuclide concentration in fucus from the La Hague area in 1996/1997 (in Bq/kg)

Sampling area	Material	Measured by	^{60}Co		^{106}Ru/^{106}Rh	
			Average	Maximum	Average	Maximum
Barfleur (1997)	Fucus	COGEMA	0.59	0.69	<2.65	<2.7
Goury (1997)	Fucus	COGEMA	1.82	2.9	<3.15	4
Anse des Moulinets (1997)	Fucus	COGEMA	1.9	2.2	<5.7	7.2
Barneville/Carteret (1997)	Fucus	COGEMA	1.16	1.5	<2.73	<3
Diélette (1996)	Fucus	EDF	2.4	2.4	1.7	1.7
Diélette (1996)	Fucus	GEA	2.14	2.27	2.02	3.01
Goury (1996)	Fucus	GEA	2.5	3.88	2.27	4.23
Anse des Moulinets (1997)	Fucus	OPRI	2.05	3	4.6	5.8
Barneville (1997)	Fucus	OPRI	1.3	1.6	<2.32	3.4
Sciotot (1997)	Fucus	OPRI	1.35	2	<3.4	<3.8
Barfleur (1997)	Fucus	OPRI	0.59	0.61	<1.49	<1.78
Flamanville (1996)	Fucus	EDF	1.6	1.6	1.3	1.3
Goury (1996)	Fucus	EDF	3.3	3.3	2.9	2.9
Carteret (1996)	Fucus	EDF	0.8	0.8	<1.1	<1.1
Gatteville (1996)	Fucus	GEA	0.88	1.1		
Barneville (1996)	Fucus	GEA	0.73	0.73		

Source: [GRNC, GT-2, 1999]

Table 25 Radionuclide concentration in royal crabs caught close to the La Hague sea discharge pipe, in 1997 (in Bq/kg)

Measured by, date	Nb of samples	^{241}Am	^{60}Co	^{134}Cs	^{137}Cs	^{129}I	^{106}Ru	^{125}Sb	^{90}Sr	^{238}Pu	^{239}Pu ^{240}Pu
ACRO, 15.9.97	3	2.2	202	n.n.	184	73	798	127	-	-	-
Univ. Bremen, 15.9.97	3	n.n.	162.2	n.n.	154	54	489	83.6	**5.120** (1)	-	**155** (1)
ACRO, 16.9.97	4	n.n.	17	n.n.	11	n.n.	<17.6	3.3	-	-	-
ACRO, 20.9.97	2	n.n.	216	n.n.	125	79	355	61	-	-	-

(1) Concentration above relevant CFILs (Community Food Intervention Levels)

Source: [Greenpeace, 1997]

Table 26 Radionuclide concentration in fucus and limpets from the La Hague area in 1997 (in Bq/kg)(1)

Sampling area	Sample type	^{238}Pu	^{239}Pu ^{240}Pu	^{241}Am	^{134}Cs	^{137}Cs	^{129}I	^{106}Ru ^{106}Rh	^{60}Co	^{131}I	^{90}Sr
Anse des Moulinets	Fucus	0.063	0.093	-	*<0.14*	<0.22	*11.55*	<5.7	1.9	*<1.08*	*<0.24*
	Limpet	0.024	0.053	<0.23	<0.08	*<0.11*	*0.64*	6.0	0.61	*<1.06*	*<0.11*
Barneville	Fucus	<0.036	0.048	<0.53	<0.19	*<0.12*	*3.75*	*<2.32*	*1.3*	*<0.24*	-
	Limpet	*0.006*	*0.010*	<0.26	<0.07	*<0.09*	*<0.36*	*<1.54*	*0.28*	*<0.59*	*<0.09*

(1) Figures in *italic* indicate measurements by OPRI, others measurements by COGEMA

Source: [GRNC, GT-2, 1999]

Table 27 Radionuclide concentration measured by COGEMA in fucus and limpets from the La Hague area in 2000 (in Bq/kg)

Sampling area	Sample type	^{137}Cs	^{129}I	^{106}Ru/^{106}Rh	^{60}Co	^{40}K
Anse des Moulinets	Fucus	-	9.0	<2.98	1.46	227.5
	Limpet	<0.42	-	4.43	-	68.5
Barneville	Fucus	-	2.4	<2.70	<0.60	287.5
	Limpet	<0.07	-	<1.02	-	77.0

Source: Database of CSPI (Commission Spéciale Permanente d'Information) La Hague

Table 28 Radionuclide concentration measured by COGEMA in fucus, molluscs and limpets in the first semester of 2001 (in Bq/kg)

Sampling area	Sample type	^{137}Cs	^{129}I	^{106}Ru/^{106}Rh	^{60}Co	^{241}Am	^{14}C (1)
Between Granville and the Seine Bay	Fucus	<0.32	5.01	<2.31	<0.84	<0.15	31.1
	Mollusc	<0.15	<0.44	<1.18	<0.25	<0.17	55.1
	Fish	0.23	<0.60	<0.78	<0.11	-	43.1

(1) Total activity (artificial + natural).

Source: COGEMA (www.cogemalahague.fr)

ANNEX 10 Specific Radiobiological Issues

During the Interim Report Meeting of the STOA Panel, on 10 April 2001 in Brussels, it was requested that a number of specific radiobiological issues should be addressed in the Final Report of the STOA Study Team.

(a) Genetic Effects

Ionising radiation can cause mutations in the DNA of male and female germ cells. These mutations will have no direct effect on the exposed individuals themselves, but may have consequences in future generations. Inherited disease in humans due to dominant or recessive mutations, or chromosome aberrations, can be quantified using epidemiological studies in humans and animal experiments. However, there is a broad category of human disorders – so called multifactorial diseases – that depend on both genetic and environmental factors.

There are no human data that demonstrate a convincing effect of genetic damage due to radiation. The children of the survivors of Hiroshima and Nagasaki have been studied in some detail, but have not demonstrated any statistically significant increase of genetic abnormalities. This does not mean, however, that there is no effect. The studies may simply reflect the relatively small sample size, thus low statistical power.

In a review of the data, Neel *et al* [1989] state that

> *"We do not regard these studies as testing the hypothesis that radiation produces mutations. It [radiation] has done so in every plant and animal species which has been properly studied with regard to this question. Rather, we feel that our challenge is to take the observed results as our best current estimate of the genetic impact of radiation on humans and consider how to organize the findings to extract the most likely genetic doubling dose suggested by the indicators."*

Neel *et al* estimated the doubling dose at between 1.5 and 1.9 Sv. This is comparable with the doubling dose obtained from animal studies (mainly mice).

In a review of this matter, NRPB [1993] concluded that:

> *"There remain many uncertainties in the formulation of risk estimates for the induction of genetic effects in man by radiation. The principal reasons for this are:*
>
> *(i) the absence of directly informative human epidemiological data and*
>
> *(ii) doubts on the relative responsiveness and hence appropriateness of some of the genetic endpoints employed in experimental animal studies.*
>
> *In the case of single gene and chromosomal mutations animal data have been used to project genetic risks to man but it may be argued that these extrapolations are likely to overestimate overall genetic risk. Uncertainties in genetic risk estimates are at their greatest in the case of multifactorial diseases. For this complex group of disorders it is clear that* ***a lack of fundamental knowledge greatly limits the capacity to provide soundly based estimates of risk****."* [emphasis added]

This last comment was reinforced by the ICRP who stated [1991] that the contribution [to the risk factor] attributable to [multifactorial diseases] can only be very approximately and tentatively estimated.

(b) Misconceptions about Genetic Effects

Contrary to commonly held beliefs, most radiation-induced mutations are not expected to be harmful. For example, no recorded instances have been found, so far, of the isolation of more virulent strains of a microorganism as a result of radiation-induced mutation of a less virulent population [Moseley, 1990]. This misconception stems from misunderstandings about effects of radiation and the nature of mutational change.

Radiation's main effects, i.e. cell death and mutation, occur through damage to cellular DNA, particularly during cell reproduction. Where damage occurs to the DNA of a somatic cell - a cancer may result: where the damage is to a germ cell, hereditary changes may occur. All life forms are subject to background levels of radiation and corresponding DNA insult: all life forms have evolved defence mechanisms for dealing with these levels of

damage. DNA repair mechanisms are formidable in number: an estimated 10,000 repairs are effected per hour in a mammalian cell [Billen, 1990; Saul and Ames, 1986]. These repairs are not always effected correctly which results in a small number of faults in the transcription of the genetic code to succeeding generations; that is, in mutations.

The term "mutation" is commonly used to refer to changes to both cells and to species. Mutations in cellular DNA are different from mutations in the phenotype (outward form or function) of a species. In cellular terms, most DNA mutations are deleterious to offspring cells and will result in their reproductive death, i.e. no colonies of the mutated cell will form. Where cell mutations survive and reproduce in a species, there will usually be a change in the phenotype of the individual. In species terms, most mutations to the phenotype which survive in viable progeny will be recessive. They may also be deleterious in which case they will be removed from the gene pool over time by natural selective pressures.

The overall process of evolution - the gradual change in species which occurs through the mutation of phenotypes, is perceived here to be beneficial (i.e. more adapted to their environment), which may appear in conflict with the fact that individual mutations are mostly deleterious. However evolution occurs over many thousands of generations; perhaps only one in many thousands of mutations is beneficial and survives.

Accordingly, all life forms experience continuing low background rates of mutations. In most cases, mutations are deleterious and are weeded out by natural selection: equilibrium is thought to exist between rates of mutation and their elimination from gene pools. Increased radiation exposures will result in an increased mutation rate in the gene pool, resulting in new equilibrium being formed.

The question remains whether the increased mutation rates from anthropogenic nuclide releases from reprocessing are justified. As far as is known, this question has not been addressed in the literature available to the authors. In essence, we are embarking on an experiment with the human genome with such large nuclide releases. The same of course is true with the genomes of all other plants and animals.

(c) Genomic Instability

In a seminal paper [Kadhim *et al*, 1992], Professor Wright and his team revealed that when mouse bone marrow cells were traversed by single alpha particles, damage to the genome could be delayed for up to six generations of cell replication.

The authors speculated that:

> *"...[if there are] classes of unique, initial radiogenic damage induced only by high-LET radiations, then the RBE for such damage would be effectively infinite. Leukaemia's arising from such a situation may not have been identified as radiogenic from human epidemiological data (which is based predominantly on considering low-LET radiation) and our findings may then have considerable relevance to the problem of low-dose radiation exposure from artificial or natural α emitters."*

After almost a decade of further research, a larger and more complex picture is emerging as described by Wright [2000]. The phenomenon has been demonstrated in human cells, is not restricted only to high-LET (Linear Energy Transfer)[60] radiation, may not be due to direct DNA damage, and may involve neighbouring cells (the "bystander" effect). More important, there may be significant inter-individual differences in susceptibility.

This adds up to what Professor Wright describes as a *"major challenge to conventional radiobiological concepts."* However Roger Clarke, Chairman of ICRP and Director of the NRPB has stated

> *"It has been claimed by some that the finding of this phenomenon poses a challenge to accepted concepts in radiological protection, and that risks may be higher than currently judged. The phenomenon has yet to be associated with tumour risk or other possible health effects. Also, even if it were to be established, there would be no obvious implications for the direct epidemiological-based central estimates of cancer risk on which risk projections are founded."* [Clarke, 1999]

[60] LET is a measure for the density of the energy deposits left by the high-speed particles along their tracks. LET is defined as the average amount of energy lost per unit of track-length. It can be measured in KeV per micrometer. X-rays, gamma rays, and beta particles are low-LET radiations because the distance

Clarke states that this phenomenon has yet to be associated with tumour risk or other possible health effects. However it would be unwise to assume there are no such associations; absence of evidence is not evidence of absence. Earlier in the same article Clarke explains the difficulty of estimating risks at low doses from epidemiological studies — i.e. insufficient statistical power. Moreover, his remark about epidemiological-based estimates of cancer risk does not mention that, (as pointed out in the Wright team's 1992 paper), current estimates are based on extrapolation from acute high doses of low-LET radiation, not chronic low doses of high-LET radiation.

It is concluded there remains much to learn about the possible role of genomic instability in radiation-induced cancer.

(d) Chronic Effects on Environment and Animals

In a letter to the Committee dated 22 January 2001, the Petitioner queried *"the long-term consequences of chronic radioactive discharges on the marine environment and the genetic material of plants and animals considering the extremely long half-lives of some of the discharged nuclides."*

Possible genetic effects of radiation are discussed in section (a) above in this Annex. As regards chronic effects of radiation, our present understanding is that radiation effects are additive: the larger the dose, the greater the effect. Many animal experiments at relatively high overall doses have shown a dose rate effect: that is, protracted doses have less effect than single doses of the same quantity. The extent to which this phenomenon is relevant in the case of the much smaller doses received from environmental discharges has been questioned by UNSCEAR [1994 and 2000].

As regards the effects of radiation on animals and the environment, current ICRP guidance is that radiation protection measures designed for humans will protect other species in the environment. This is partly based on the observation that, as regards taxonomic orders and kingdoms, species which are more complex and have evolved furthest (including humans) are, generally speaking, the most radiosensitive, mainly due to their larger DNA cross-sections and increased cell differentiation. However the ICRP's view is under review and a number of major studies are underway. .

Rose [1989] has comprehensively reviewed radiation effects in species other than man. For fatalities, the review reported that the lowest ***chronic*** exposure resulting in death was 3.6 Gy[61] per year (~0.36 mGy per hour) for several rodent species. The lowest ***acute*** dose was 0.8 Gy, which led to the death of a small proportion of young Douglas fir trees. These ***acute*** doses are considerably lower that those used for humans, for whom the LD_{50} is conventionally accepted to be 4 to 6 Gy.

For teratogenic or genetic change, the lowest ***chronic*** exposure was 3 mGy per year (~0.3 mGy per hour), which reduced birth mass and increased brain mass of laboratory rats irradiated as fetuses during the final third of intra-uterine life. For ***acute*** exposures, a dose of 10 mGy to pregnant rats impaired the reflexes of their offspring.

For changes in behaviour or development, the lowest ***chronic*** exposure was around 10 mGy per year (i.e. 1 microGy per hour), which can be detected by planarium worms and mud snails. For ***acute*** exposures, a dose of only 1 microGy caused a transient reduction in the growth-rate of a mould: cockroaches whose eyes have adjusted to the dark can visually detect this dose.

[61] A Gy or gray is a unit of radiation dose equal to a Sv or sievert for gamma radiation. Note that 1G = 1,000 mGy = 1,000,000 µGy.

ANNEX 11 Possible Causes for the Discrepancy between Observed Cancers and Estimated Low Doses

With regard to the estimated low doses to those working or living near Sellafield, it is surmised that:

- the estimated low doses are incorrect, or
- the estimated risk factor for radiation-induced cancer is incorrect, or
- the concept of "dose" or "equivalent dose" does not correctly reflect the level of damage by radiation from ingested or inhaled nuclides.

These matters are examined in turn below.

(a) Dose Assessments

The estimation of radiation doses received from discharged nuclides requires:

- accurate measurements of body burdens or nuclide contamination of food, water and the environment:
- transport models to predict the movement of nuclides through the environment:
- metabolic models to predict the uptake, retention, and excretion of nuclides in the body:
- dose conversion factors:
- radiation weighting factors.

These models and factors, and their predicted radiation doses, are in some cases conservative, (i.e., they result in deliberately high estimated doses to allow for a margin of error). Others are less so.

All contain areas of ***uncertainty***, as discussed by the Committee on the Medical Aspects of Radiation in the Environment [COMARE, 1986] following the 1983 Black Report into the incidence of leukemias at Sellafield; by Sir Richard Southwood [1993] former chairman of the National Radiation Protection Board (NRPB); and by the 4th COMARE report [1994].

The 4th COMARE report made specific recommendations for further radiation research to reduce these uncertainties, including the following

1. Uncertainties in estimating radiation doses and effects for particular target cells from:
   (a) internal exposure to radionuclides in the developing embryo and fetus
   (b) internal exposure to radionuclides in tracheobronchial lymph nodes.
   (c) biological hazards of ultra-short-range radiations including Auger emissions
2. Uncertainties in the differences between biological effects of radiations of differing quality
3. Information on the specific nature of early molecular radiation events in somatic or germ cells that contribute to cancer initiation or development. Particular information is required on
   (a) the genetic basis of differences in radiation sensitivity in somatic or germ cells
   (b) the nature of radiation-induced high frequency events in somatic or germ cells
   (c) and the relevance to disease of
   (d) radiation-induced mini-satellite mutations in somatic and germ cells
   (e) radiation-induced genetic instability in somatic or germ cells
4. Information on mechanisms of interaction between radiation and other agents.

An important source of uncertainty is the estimation of *in utero* exposures, as emphasised by GRNC in their report

> *"In the absence of an international consensus on exposure models for the foetus and embryo, the risk of radiation-induced leukaemia associated with exposure received in utero could be estimated only for the routine discharges from local nuclear facilities, as a sensitivity analysis. For the cohort as a whole, taking the in utero doses into account increased the number of estimated cases*

of radiation-induced leukaemia by roughly 33% compared with consideration of only the exposure received during childhood. This substantial percentage underlines the need for a valid exposure model for calculating in utero doses in future radioecological studies" [Rommens, 2000].

At a Consultative Exercise on Dose Assessments organised in October 2000 by the UK Food Standards Agency, it emerged that a sound basis still does not exist for estimating foetal doses: an ICRP task group is presently considering this [CEDA, 2001; see comment by Thorne, page 21]. The matter could be important, as evidence points to the initiation of childhood leukaemia originating *in utero* [CEDA, 2001; see comment by Bridges, page 21].

(b) Radiation Risk Factors

Risk factors for radiation-induced cancer are derived mainly from studies of the survivors of the atomic bombs dropped on Japan in 1945. In its most recent review of this issue (in 1990), ICRP recommended a risk factor of 5% (0.05) per Sv for radiation-induced fatal cancer. This is an approximately three-fold increase over the pre-1990 accepted value. Although this factor may be changed in the future to take into account new data, any future changes in risk estimates are unlikely to explain the excesses of childhood cancer around Sellafield and La Hague.

(c) Parameter of "Dose"

Uncertainty remains over the parameter of "dose" itself, and what it measures. The unit of absorbed dose is the Gray, defined as the averaged deposition of one joule of energy in one kilogram of tissue. A kilogram of tissue typically will be of decimetre dimensions (10^{-1} metres). But a cancer may be initiated through a single adverse change to the DNA of a single cell nucleus [NRPB, 1995]. The cross-section of DNA, the target structure for radiation's adverse effects, is of nanometer dimensions (10^{-9} metres). The difference between where dose is measured (i.e. tissues or organs) and where radiation exerts its effects is about eight orders of magnitude, i.e. a 100,000,000-fold difference.

This discrepancy normally doesn't matter where large numbers of photons or particles are averaged over organs or whole body masses. "Dose" is accurate enough for external radiation, e.g. X-rays and gamma rays; also for internally deposited nuclides whose photon energies of disintegration are large and distributed evenly throughout tissues and cellular structures. But "dose" is less accurate in the case of low concentrations of nuclides whose disintegration results in particles with very short tracks, e.g. alpha emitters, low energy beta emitters and Auger emitters. (Although low, these energies, if deposited near target structures, are easily large enough to disrupt DNA.)

Alpha emitters, such as plutonium, and low energy beta-emitters, such as tritium (the radioactive isotope of hydrogen) and carbon-14, are all discharged from reprocessing plants. Their distribution within cells or organs becomes critical and to the extent that they are not uniformly distributed between and within cells, there is scope for question about the accuracy of their "doses". There is evidence of heterogeneous distribution within cells in the case of tritium [Fairlie, 1992] and for heterogeneous distribution within organs with plutonium [EPA, 1993]. The implication is that the heterogeneous distribution of ingested, absorbed or inhaled nuclides could result in a small estimated "dose", but a large effect on target structures within cell nuclei.

It is recommended that more research should be carried out on the distribution of low energy nuclides within cell nuclei structures. The measurement of radiation's effects within small volumes is termed microdosimetry. Unfortunately, the study of microdosimetry over a number of decades has not resulted in practical recommendations for radiation protection.

ANNEX 12 Evolution of the Waste Stockpiles Managed at La Hague

Table 29 Evolution of the Waste Stockpiles, Conditioned and non Conditioned, Managed at La Hague (1993-1999)

	12.1993	12.1994	12.1995	12.1996	12.1997	12.1998	12.1999
Cumulated amount of spent fuel reprocessed (tonnes)	*5,721.2*	*6,997.5*	*8,556.2*	*10,237.1*	*11,907.0*	*13,535.7*	*15,097.2*
Conditioned wastes							
Bituminised waste (drum)	7,610	8,592	9,177	9,471	9,624	9,805	9,898
Hulls and nozzles (drum) (1)	720	1,119	1,759	2,431	3,060	3,658	4,249
Cemented technological waste (drum)	9,116	9,224	8,158	6,589	5,144	4,563	4,311
Waste contaminated with alpha emitters (drum) (2)	4,639	4,858	5,043	4,984	5,019	4,363	3,958
Canisters of vitrified waste	2,400	2,896	3,692	4,555	5,382	6,291	6,759
Non conditioned wastes							
Hulls, nozzles, and other ILW (tonnes)	2,234.8	2,254.9	2,250.1	2,230.1	2,231.5	2,254.2	2,245.4
Magnesium, graphite and metal (m^3)	2,971.8	2,972.8	2,972.8	2,972.8	2,972.8	2,975	2,930
Sludge (m^3)	12,757	11,769	10,647	9,688	9,264	9,264	9,288

(1) On the total of 4,249 drums of conditioned hulls/nozzles, 2,731 drums are to be re-conditioned in the future compacting ACC workshop (planned for 2001).
(2) Some of these waste are planned to be re-conditioned.

Source: National Inventories of Radioactive Wastes, *ANDRA, 1994-2000*

ANNEX 13 The Return of Foreign Waste from Reprocessing at La Hague

Table 30 Approval by the Foreign Clients of the COGEMA's Specifications for Waste Conditioning

	Vitrified waste	Cemented hulls and nozzles	Bitumized sludge	Cemented technological waste
Japan	Yes	Yes	Yes	Yes
Germany	Yes	Yes	Yes	Yes
Belgium	Yes	**No**	**No**	**No**
Switzerland	Yes	Yes	Yes	Yes
Netherlands	Yes	**No**	**No**	**No**

Source: Comité de Défense Civil, Guernsey,June 1995

Table 31 Timetable for the R eturn of the Reprocessing waste (1) – the German Case

	Number of transports		
Waste / Container	**HLW - Vitrified waste CASTOR HAW 20/28CG**		**Compacted waste CASTOR CSDC 28**
Contracts	**COGEMA**	**BNFL**	**COGEMA(2)**
< 1999	3 containers	–	–
2000	0 containers	–	–
2001	12 containers	–	–
2002	12 containers	–	–
2003	12 containers	–	–
2004	12 containers	6 containers	–
2005	12 containers	6 containers	–
2006	12 containers	6 containers	–
2007	12 containers	6 containers	–
2008	12 containers	6 containers	6 containers
2009	12 containers	6 containers	12 containers
2010	12 containers	3 containers	12 containers
2011	4 containers	–	18 containers
2012	–	–	24 containers
2013	–	–	24 containers
2014	–	–	24 containers
2015	–	–	24 containers
2016	–	–	24 containers
2017	–	–	24 containers
2018	–	–	24 containers
2019	–	–	24 containers
2020	–	–	24 containers
2021	–	–	24 containers
2022	–	–	24 containers
Total	**127** containers	**39** containers	**312** containers

(1) This table does **not** include the large amounts of low level radioactive waste as well as the bituminised waste drums already produced which, according to the French legislation, should also be returned to Germany.

(2) 1,5 container of compacted waste/t of U (figures from the terms of the contract of compacting). One should note that this figure corresponds to the future compaction rate of the ACC workshop according to COGEMA, which is by a factor 4 to 5 lower than the previous figures of hulls/nozzles waste production. Initially planned to start in 1999, the ACC workshop has not started at the end of March 2001.

Source: GNS, 10.2000

ANNEX 14 Compared Discharge Limits of La Hague and a Typical Reactor Site

Table 32 Comparison of Discharge Limits for the La Hague Site, and the Nuclear Power Plants of Saint-Laurent-des-Eaux and Flamanville

	La Hague	Saint-Laurent	Flamanville	Ratio
Type of Effluent	**Authorisation for the whole site (in GBq)**	**Authorisation for 2 PWR 900 MWe (in GBq)**	**Authorisation for 2 PWR 1,300 MWe (in GBq)**	**La Hague vs. 1 PWR Flamanville** (3)
Gaseous Releases (1)				
Gases other than tritium	480,000,000	37,101	46,401	**20,689**
Tritium	2,200,000	4,000	5,000	**880**
Halogenes (iodine, chlorine…)	110	0.8	0.8	**275**
Aerosols	74	–	–	**–**
Liquid Discharges				
Radio elements other than tritium	1,700,000	330	425	**8,000**
Tritium	37,000,000	45,000	60,000	**1,233**
Strontium-90 et caesium-137	220,000	–	–	**–**
Alpha emitters	1,700	**prohibited** (2)	**prohibited** (2)	**–**

(1) There are no specific gaseous alpha discharge limits for La Hague (although the plutonium is included in the aerosols, except for the Pu-241).
(2) The discharge of gaseous or liquid alpha emitters is prohibited at the reactor sites of Saint-Laurent-des-Eaux (Arrêté du 2 février 1999) and Flamanville(Arrêté du 6 juin 2000).
(3) The Flamanville site is 17 km of the La Hague site on the same coast.

Source: Journal Officiel de la République française.

ANNEX 15 Compared Real Radioactive Discharges from La Hague and One PWR

Table 33 Comparison of Real (1) Radioactive Discharges from La Hague and Flamanville, 1999

Category	Flamanville (2x1,300 MW) 1999 (GBq)	La Hague 1999 (GBq)	Ratio (2) La Hague vs. 1 PWR Flamanville
GASEOUS RELEASES			
Alpha Emitters	not authorized	$1.82\ 10^{-3}$	-
Noble Gases, Aerosols	15,000	300,000,000	40,000
Tritium ^{3}H	*1,266*	80,000	*126*
Carbon-14	*337*	19,000	*113*
Iodine	0.41	8.16	42
Sum of other radionuclides		0.27	
Total of gaseous releases	**16,603**	**300,099,008**	**36,150**
LIQUID RELEASES			
Alpha Emitters	not authorized	60.32	-
Carbon-14	*15.3*	9,930	*1,298*
Tritium ^{3}H	25,000	12,900,000	1,032
Iodine	2.2	1,845	32,918
Sum of other radionuclides		34,364	
Total of liquid releases	**25,017**	**12,946,199**	**1,034**
Total of releases	**41,612**	**313,045,208**	**15,046**

(1) Radioactivity released by category as indicated by the plant operator on the basis of his own measurements for the year 1999. Quantities indicated in *italic* are based on estimates for Flamanville releases of tritium in gaseous releases and carbon-14 in both gaseous and liquid releases, because those were not measured by EDF before the beginning of 2001. These estimates are calculated as follows: figures given by EDF for January 2001 releases of tritium (gas) and carbon-14 (liquid and gas) provide an evaluation of the year 1999 releases using the ratio between the total production of the site in January 2001 (1,739 TWh) and during the entire year 1999 (14,205 TWh).

(2) Although this does not modify the orders of magnitude, it should be stressed that this ratio corresponds to a year, 1999, when Flamanville had a load factor of only 60.9%, while the La Hague plants of UP2-800 and UP3 reached a load factor of 97,6% (1,561.5 t for a nominal capacity of 1,600 t).

Source: COGEMA, 2000; CNPE Flamanville, 2001

ANNEX 16 Chronological List of 8 Significant Accidents at La Hague since 1968

• **02 October 1968:** ***Iodine release through the UP2-400 chimney.***

Source: [GRNC, GT-1, 1999]

An abnormal rate of gaseous iodine-131 (^{131}I) release was detected at the UP2-400 factory. The release exceeded the limit (370 Bq/s) by a factor of 10.000. This high level of iodine-131 release (37,000 Bq/s) has continued for eight hours and has then been decreasing for 15 hours before the activity fell to a level under the authorised limit.

The total amount of iodine-131 released was evaluated at 185 GBq (the current authorisation for iodine is 110 GBq per year). This accident was caused by the treatment of insufficiently cooled gas-graphite fuels. A release of iodine-129 (^{129}I) was reported as well (7,4 GBq) so that the total release reached twofold the annual authorisation for halogens. No evaluation of the impact on public health was established.

• **14 January 1970:** ***Explosion during processing of Gas-Graphite fuel.***

Source: [GRNC, GT-1, 1999]

During the chemical dissolution of the fuel, the temperature of the reaction increased sharply and an explosion due to hydrogen gas emanation (H_2) occurred. The filters of the chimney recorded an activity of 5,900 GBq, mainly due to antimony-125 (^{125}Sb), 95%, and iodine-131 (^{131}I), 5%. The iodine-129 activity released was 2,7 times higher than the annual authorised limit (110 GBq). No measurements in the environment were undertaken following this accident, no evaluation of the impact on public health has been carried out.

• **01 October 1976:** ***Contamination of the "Sainte-Hélène" stream and other streams close to LaHague***.

Source: [GRNC, GT-1, 1999; GSIEN, 1992; ACRO, 2000a]

A bad designed packaging of tritium (^{3}H)-rich wastes allowed large amounts of tritium to be released in the "Sainte-Hélène" stream: the tritium activity reached 7,400 Bq/l in October 1976. Streams outside nuclear areas usually exhibit a level below 1 Bq/l. From 1977 to 1983, the mean annual tritium activity released is about 5,000 Bq/l. These unexpected high levels of contamination were due to the leakage. The operations of re-packaging gave rise to the release of 52,000 GBq of tritium, which represents five times the annual release of tritium at this period. Moreover, measurement devices taken into account to monitor radioactivity are not representative for the localisation of main tritium contamination.

Many other radionuclides were detected over time in this stream like strontium-90 (^{90}Sr), caesium-137 (^{137}Cs), cobalt-60 (^{60}Co). Caesium activity in sediments was found to be 10 times higher in 1991 than usual. Some other evidence of contamination is reported by local independent laboratories (ACRO, CRII-Rad[62]).

• **02 January 1980:** ***Discharge pipe leakage.***

Source: [Guillemette, 1999; ACRO, 2000a]

A one meter long through-wall crack has been discovered on the La Hague discharge pipe at about 200 meters from the shore. The radiological impact had been under-estimated as has been revealed later by a member of the Permanent special commission for information (CSPI La Hague). Individuals of the critical group (fishermen) received 3.5 times the annual authorised dose (namely 3,486 mSv, to be compared with the current European limit of 1 mSv/year).

A radiological measure on mollusc done by the CFDT union of La Hague in 1980 shows a 200-fold difference with COGEMA analysis carried out during the same period : 407 Bq/kg of strontium-90 (^{90}Sr) detected in molluscs instead of 2 Bq/kg as reported by COGEMA.

[62] ACRO: Association pour le Contrôle de la Radioactivité dans l'Ouest.
CRII-Rad: Commission de Recherche et d'Information Indépendantes sur la Radioactivité.

• **06 January 1981:** ***Fire in waste silo***.

Source: [GRNC, GT-1, 1999; BSN, 1981] and http://nucleaire.edf.fr

Graphite elements had been burning for 24 hours in a waste silo. Uranium metal caught fire following a mechanical shock during operations. The maximum measured level of air contamination, 700 Bq/m^3, was reached 10 hours after the beginning of the fire.

The released activity is mainly due to caesium-137 and -134 (^{137}Cs and ^{134}Cs) and ranges between 740 GBq and 1,850 GBq, thus 10 times of more the annual limit. The annual limit for the whole La Hague site is 74 GBq of caesium-137. Strontium-90 (^{90}Sr) was detected in rainwater and the authorised limit of surface contamination was reached in 6 km distance from the site. A worker received in one day the annual admissible dose, 50 mSv. An off site health impact has not been carried out.

This fire was considered a major accident and was rated later at level 3 of the International Nuclear Event Scale, INES (which has 7 levels).

• **13 February 1990:** ***Uncontrolled release of caesium-137 (^{137}Cs) by the ELAN II B plant chimney***.

Source: [CILH, 1990]; *Bulletin de sûreté nucléaire*

A routine replacement of a chimney filter has led to the release of non-filtered and contaminated air for 10 minutes. An estimated 3,7 MBq of caesium-137 have been released in the atmosphere. A specific limitation for caesium-137 does not exist. No evaluation of the radiological consequences was carried out. This accident was classified at level 1 of the International Nuclear Event Scale.

• **11 March 1997:** ***Irradiation caused by the discharge pipe at low tide***.

Source: [ACRO, 2000a]; *Contrôle,* June 1997

An independent laboratory (CRII-Rad) measured a high level of dose equivalent rate, close to the discharge pipe at low tide. COGEMA confirmed the high value of 0,3 mSv/hour (which gives an individual the annual dose in three hours and half only). The safety authority rated this event at level 1 of INES since the pipe provided an *"unacceptable potential risk of irradiation for public."* With this exposure and the strontium-90 (^{90}Sr) concentration reached inside the pipe, the vicinity of the pipe would have required a classification of "nuclear facility" in accordance with French legal framework on radioprotection.

• **Since 1983:** ***Permanent pollution due to strontium-90 (^{90}Sr)***.

COGEMA said that strontium-90 contamination was caused by metallic waste stored in concrete pools which released radionuclides in groundwater and near-by streams. As of the end of 1999, the contamination is still detected [ACRO, 2000b]: 20 Bq/l in 1991, between 5 and 10 Bq/l since then (maximum admissible concentration in drinking water : 36 Bq/l). Moreover, strontium-90 has a great affinity for bones and bone marrow. In a context of an excess of leukæmia cases found in North-Cotentin [see epidemiological studies of Viel; and Spira *et al*], it seems abnormal that no specific monitoring of gaseous strontium-90 is carried out by COGEMA, as Pierre Paris, vice-president of ACRO, notes in a letter to the CSPI La Hague (October 8th, 2000).

ANNEX 17 Incidents/Accidents at La Hague declared to the French Safety Authorities between 1989 and 2000

The incidents declared by COGEMA to the French nuclear safety authorities are rated on the International Nuclear Event Scale (INES), that reaches from level 0 to level 7, since March 1989. Here is a selection of incidents/accidents that the operator COGEMA has declared to the safety authorities between 1989 and the end of the first semester of 2001 and that were published by the safety authorities.

• 2001:

3 incidents declared in the first semester of 2001 . These are:

18 May: A breakdown of a ventilation system at the R7 vitrification plant (INES 1). The incident coincided with the sticking of a valve on the emergency ventilation, which ended up in the release of radioactive materials into the environment. COGEMA announced that the measures taken at the chimney that day indicated a source term of 11 MBq. Yet, ACRO undertook measures shortly after the incident was made public. According to its calculations [ACRO, 2001], within one hour, COGEMA released nearly 100 times as much gaseous effluents as it did in total in 1999, when it reached its record level (153 MBq), and approximately 10 times as much as the annual limit it committed itself to comply with, in 2000 (1,850 MBq). For the safety authority, the DSIN, the measures undertaken on the environment confirm that the incident had no significant consequences neither on the populations' health nor on the environment. It affirmed that a dose received by an observer, at one kilometer from the site, would have been of the order of a few microsieverts, compared to the regulatory 1 mSv/year limit.

24 February: Leakage of a radioactive liquid solution into the drip tray pit during a rinsing operation at the R1 shearing plant (INES 1). The incident was due to a watertightness fault in the chute connecting the shearer to the dissolver. The Safety authority came to the conclusion that the incident had no consequences on the populations' health and/or on the environment.

5 January: Non-compliance with the exploitation regulations for the storage of plutonium oxide powder at the BST1 plant (INES 1).

• 2000:

18 incidents declared in 2000 . Amongst these are:

16 December: Irradiation of an employee at the vitrification plant R7 (INES 1). The cap of a well that contains vitrified High Liquid Waste had not been put back and a worker was not aware of it. The dosimeter of the worker was not running while the dose rate reached 660 mSv/h above the well.

7 December: Temporary loss of the ventilation at the vitrification plant R7 (INES 0).

30 November: Flaw in the fire emergency system at R7 plant (INES 0).

12 October: Irradiation of a worker at UP2-400 plant (INES 1).

11 October: Fire in the decommissioning cell of the R7 facility (INES 0).

• 1999:

17 incidents declared in 1999 . Among them:

17 October: The concentration of fissile materials in the dissolution tank of UP3 was not checked before continuing the process. This measurement is necessary to insure that there is no criticality risk (INES 1).

24 September: A worker died during a maintenance operation on a transport cask. A second one was hospitalised. This accident was not classified on the INES scale.

16 August: Loss of water-tightness of a transfer pipe in the UP3 plant. The quantity of plutonium exceeded authorised limits of the plant (INES 1).

25 June: The activity of a spent fuel storage pool "C" in UP2-800 exceeded the authorised limit after the transfer of leaking fuel assemblies (INES 1).

28 May: Loss of air-tightness of the first containment barrier at the vitrification plant T7 (INES 1).

20 May: Damage caused near the discharge pipe (not rated on the INES scale).

• 1998:

15 incidents declared in 1998 . Among them:

9 December: Measurements of fissile materials concentration in the dissolution tank T1 of UP3 plant had not been carried out (INES 1).

6 November: Contamination of the clothes of workers during operation on discharge pipe (INES 0).

4 June: Flaw in the flow of dissolution, centrifugation out of order (INES 1).

19 May: Inspections on the spent fuel stored in the NPH pool of UP2-400 were conducted without respecting basic safety rules (INES 0).

23 April: Uncontrolled release of radioactive particles at the chimney of UP2-400 (INES 0).

20 February: Irradiation of two workers in UP3. The door of an irradiating cell was kept inadvertently open (INES 1).

• 1997:

13 incidents declared in 1997 . Among them:

17 October: Six assemblies were stored without authorisation in the pool "D" of UP3 (INES 1).

4 September: Recurrent contamination of workers during maintenance work at T2 plant (INES 1).

16 June: Contamination of workers at T2 plant (INES 0).

22 May: Mechanical dysfunction of the elevator of the spent fuel assemblies above the storage pool of the T1 plant (INES 1).

13 March: Leakage undetected at the dissolution tank of HAO (UP2-400). Accumulation of 260 kg of uranium nitrate, plutonium and fission products.

12 March: Contamination of workers at T2 plant (INES 0).

11 March: Irradiation caused by the discharge pipe at low tide (INES 1, see ***Annex 16***).

• 1996:

17 incidents declared in 1996 . Among them:

18 November: A fuel assembly fell down while it has been transferring from the storage pool to the dissolution tank (INES 0).

10 October: Fire in the R2 plant (INES 0).

2 October: Recurrent dysfunction of the last containment barrier filters (INES 0).

14 July: Error in the process of dissolution. Solutions were not changed before another one was added giving rise to a potential risk of criticality (INES 1).

10 July: Death of a worker by inhalation of carbon mono-oxide (not rated on the INES scale).

• 1995:

No incident declared [? or published?].

• 1994:

12 December: Overflow during the transfer from the dissolution tank of 900 litres of solution (UP2-800). The solution, which contained plutonium, fission products and uranium, was introduced while the reception tank was not empty (INES 1).

***11 August**:* Overflow caused by an excess flow of solution in the dissolution tank at UP2-400 (INES 1).

• 1989-1993:

***22 March 1993**:* Malfunction of the dissolution process at UP2-400 (INES 1).

***20 November 1992**:* Plutonium and uranium concentrations in excess inside the dissolution tank of HAO, UP2-400 (INES 1).

***31 October 1992**:* Malfunction in the dissolution process at UP3 (INES 1).

***27 September 1992**:* Dispersion of radioactive materials inside HAO plant (UP2-400), contamination of a worker (INES 1).

***17 April 1992**:* Criticality risk in the dissolution tank of HAO (UP2-400) caused by an excess of processed assemblies (INES 1).

***March 1992**:* Incident during a maintenance operation at UP2-400 plant (INES 1).

***5 July 1991**:* The filtration system in the storage pool "E" of UP3 stopped, following an electricity cut off (INES 1).

***20 June 1991**:* Fire in AT1 plant (INES 1).

***18 April 1991**:* Contamination in HAO, release of caesium and ruthenium by the chimney of the plant (INES 1).

***20 March 1991**:* The transfer of four assemblies between the unloading pool and the storage pond of HAO was accidentally blocked by the shutdown system between the two pools (INES 1).

***19 December 1990**:* Abnormal gaseous release by the chimney of the effluent treatment station STE3 (INES 1).

***10 September 1990**:* An electricity cut off made the ventilation system of HAO inoperative (INES 1).

***28 May 1990**:* Waste drum inadvertently containing a flammable organic liquid. The press designed to compact solid wastes in UP3 was damaged (INES 1).

13 February 1990**:* The routine change of the Elan II B filters gave rise to an uncontrolled release of radioactivity (Caesium 137) by the plant chimney (INES 1, see ***Annex 16).

***16 August 1989**:* Abnormal increase of radioactivity at the R7 vitrification workshop of UP2-800 plant. Evacuation of workers (not rated on the INES scale).

***8 August 1989**:* Electricity cut off at UP2-400. Control systems of gaseous releases and cooling systems of fission products tanks were disabled (INES 1).

***1 August 1989**:* Contamination of a worker during the transfer of a pump. A contaminated liquid was spread inside the MAPu workshop of UP2-400 plant and contaminated the worker (INES 1).

***28 May 1989**:* Leakage on a pipe inside UP2-400 causing an increase of the plutonium and uranium concentrations in a high activity dissolution tank (not rated on the INES scale).

***29 March 1989**:* Corrosion and subsequent leakage on the pipes of the bituminisation plant, STE3 (not rated on the INES scale).

***14 March 1989**:* Electricity cut off for the whole site of La Hague for about one hour (INES 2).

ANNEX 18 Type of Accidents and Consequences at Reprocessing Sites

Table 34 Type of Accidents with Liquid and/or Gaseous Releases at Reprocessing Sites and Occurences in Reprocessing Plants

Type of accident	Liquid releases	Gaseous releases	Occurrence
Criticality in dissolution tank	X	X	Windscale, 1973 (level 4) Tokai(1), 1999 (level 4)
Fire		X	La Hague, 1981 (level 3) Karlsruhe, 1985 Tokai, 1997 (level 3)
Explosion		X	Savannah River, 1953 Kyshtym, 1957 (level 6) Oak Ridge, 1959 La Hague, 1970 Savannah River, 1975 UTP, Ontario, 1980 Tomsk-7, 1993 Tokai, 1997 (level 3) Hanford, 1997
Filtration default of liquid releases, breach in releases structures	X		La Hague, 1979-1980 Sellafield, 1983
Loss of coolant		X	Savannah River, 1965 La Hague, April 1980 (level 3)

(1) The September 1999 accident of Tokai Mura does not concern a reprocessing plant but is remarkable because of the very generic nature of the accident, which could typically occur in a reprocessing facility [see http://www.wise-paris.org/introournews.html for more information on the Tokai Mura accident]

Radiological consequences of some of the accidents listed above

One of the most important accidents in a reprocessing plant is the 1957 explosion at the **Chelyabinsk-65** nuclear complex, which engendered the evacuation of 10,000 people in a 1,000 km^2 area. In the evacuated area, the concentration of strontium-90 exceeded 3 Ci/km^2 (111,000 Bq/m^2). Contamination in the surrounding area of 15,000 km^2 (occupied by 270,000 people) revealed concentrations of strontium-90 of 0.1-3 Ci per square km.

The fire plus explosion which occurred at **Tokai Mura** bitumenisation facility in March 1997 contaminated 37 workers while an area of 1 km^2 around the plant was evacuated.

The Tokai Mura criticality accident is exceptional because of its off-site effects. The evacuation area extended to 350 m around the plant and people were ordered to stay at home in a surrounding area of 10 km. As of 30 October 2000, Japan STA reported 667 people exposed to radiation. Two out of three workers directly implied in the accident have died. In total 73 people received doses between 45 and 50 mSv, 200 people received dose between 20 and 25 mSv, 103 people received dose between 15 and 20 mSv and 60 people received doses between 5 and 10 mSv. Contamination by iodine-131 has been detected in drinking water and milk (max. 300 Bq/kg) as well as in food (max. 200 Bq/kg), according to CNIC (Citizen's Nuclear Information Center), Japan.

ANNEX 19 Comparison of Caesium-137 Contained in Spent Fuels Stored at La Hague and Released During the Chernobyl Accident

(a) Estimation of Caesium-137 Stored at La Hague

Table 35 Fuel Storage at La Hague (as of 31 May 2001, in tons of heavy metal tHM)

	France	Germany	Belgium	Switzerland	Netherlands	Australia
Spent LWR	6,846.7	176.5	45.2	94.5	20.6	0
Spent REPU	17.9	1.4	0	0	0	0
Spent MOX	164.4	48.9	0	0	0	0
Spent MTR	0.32	0	0.22	0	0	0.15
Fresh MOX	81.6	9.6	0	0	0	0

Source: COGEMA (www.cogemalahague.fr)

With a total of fuels stored of 7,507.99 tHM, caesium-137 contained in La Hague spent fuel storage[63] is 7.58 tons.

(b) Release of Caesium-137 During the Chernobyl Accident

Conservative figure for caesium-137 fraction released: 85 PBq (for 280 PBq in core) [NEA, 1995]. Therefore caesium-137 released[64] from the Chernobyl accident was about 26.4 kg.

(c) Possible Impact of Caesium -137 in Case of a Major Accident at La Hague Cooling Ponds

The worldwide impact of the Chernobyl accident has been estimated to 600,000 man.Sv, of which around 75% due to caesium-137 alone (from 60% for Southern countries to 75% for Northern countries which are the most concerned areas in terms of impact, by the Chernobyl accident)[65] [UNSCEAR, 1988; see Annex D]. Considering the 75% share of caesium-137 in the total collective dose received from the Chernobyl accident, it can be estimated than the worldwide impact of the Chernobyl caesium-137 release alone is around 450,000 man.Sv.

In the following calculations, we consider the smallest UP3 cooling pond, or D pond, of 3,490 t of capacity and a 50% load factor.[66] The potential for a zirconium "fire", following a loss of water, arises from the packing of fuel pools to high densities [Thompson, 2000a]. A loss of water accident in the D cooling pond could lead, because of exothermic oxidation reactions of zirconium and other metals, to an accidental release up to 100% of the total caesium-137 contained in the 1,745 t of spent fuels stored [NRC, 2000]. This release would be equivalent to 1,762.1 kg of caesium-137, or 66.7 times the total caesium-137 release as a consequence of the Chernobyl accident.

Assuming identical dispersion and impact pathways in the cases of the hypothetical La Hague accident and the Chernobyl accident, the collective dose impact of the caesium-137 during the La Hague D cooling pond accident can be estimated to some 30,000,000 man.Sv or 50 times the collective dose impact of Chernobyl. Considering the ICPR-60 figure of a 5% risk of fatal cancer per Sv [ICRP, 1991] it can therefore be estimated that the caesium-137 release during a major accident such as the loss of coolant in the D cooling pond of La Hague, could cause up to 1,5 million fatal cancers.

[63] With caesium-137 activity in one ton of spent UOX with a burnup of 33 GWd/t, 3,25% of initial U-235 enrichment and 3 years of cooling period: $8.78\ 10^4$ Ci/t = $3.25\ 10^{15}$ Bq/t

[64] With caesium-137 activity: $3.2174\ 10^{12}$ Bq/g [from *Vade Mecum du technicien nucléaire*, tome 2, Ed.1980].

[65] The share of the collective dose is 53% in European coutries, 36% in the former USSR, 8% in Asia, 2% in Africa.

[66] That is a realistic assumption considering that currently a total of 7,508 t of spent fuel are stored at La Hague for a total capacity of 13,990 t.

ANNEX 20 Concentration Factors for Selected Radionuclides

Table 36 Concentration Factors of Some Key Radionuclides Released by Reprocessing Plants

	Tritium ^{3}H	**Iodine-129** ^{129}I	**Technetium-99** ^{99}Tc	**Carbon-14** ^{14}C
Half-life (years)	12	$15.7\ 10^{6}$	214,000	5,730
Concentration factor (**seaweed**) l/kg fresh	1	10,000	30,000	5,000
Concentration factor (**shellfish**) l/kg fresh	1	100	1 300	5,000
Concentration factor (**mollusc**) l/kg fresh	1	100	400	5,000
Concentration factor (**sediments**) l/kg dry	1	500	100	2,000

Source : [GRNC, GT-3, 1999]

ANNEX 21 Comparison between the Morbidity Observed in the District of Cherbourg and in the District of Avranches

Table 37 Observed and Expected Cancer Cases in the District of Cherbo urg and the District of Avranches for the years 1979-1980-1981

Cancers	Cherbourg[1] observed/expected cases	SIR[3]	Avranches[2] observed/expected cases	SIR[3]
Men				
Oral cavity, pharynx	138 / 117,6	117	87 / 96,1	91
Œsophagus	87 / 94,8	92	92 / 79,4	116
Stomach	87 / 75,1	116	63 / 63,4	99
Colon, rectum	91 / 96,6	94	84 / 82,0	102
Respiratory organs	214 / 147,3	145	74 / 121,9	61
Leukæmias	33 / 26,9	123	16 / 21,8	73
All cancers	937 / 867,5	108	622 / 722,8	92
Women				
Œsophagus	6 / 7,5	80	9 / 6,5	138
Stomach	45 / 49,4	91	54 / 43,1	125
Colon, rectum	93 / 87,9	104	73 / 78,1	93
Bronchial tubes	16 / 11,0	145	4 / 9,3	43
Breast	196 / 178,5	110	154 / 148,7	104
Neck of the womb	41 / 40,3	102	26 / 32,8	79
Leukæmias	20 / 14,9	134	6 / 11,8	51
All cancers	625 / 659,8	95	571 / 557,9	102

(1) Cherbourg is localized in the North-Cotentin, 15 km away from La Hague (North of the Manche département).
(2) Avranches is 150 km at the South of La Hague plant (South of the Manche département).
(3) SIR: Standardized Incidence Ratio (number of observed cases / number of expected cases x 100). *"When the SIR is beyond 120, it means that* […] *the number of new cancer cases has been beyond the average of the département* [Manche] *for these three years* [1979-1980-1981]*."*

Source : "Le cancer dans la Manche, 1979.1980.1981", Observatoire Régional de la Santé de Basse-Normandie

ANNEX 22 Individual Committed Dose for Six Reference Groups near La Hague (GRNC Estimates)

Table 38 Individual Committed Dose in 1985 and 1996 near La Hague for Six Reference Groups, as calculate by Radio-ecological Group of North-Cotentin (in microSievert, µSv)

Scenarios	1985 (µSv)	1996 (µSv)	Main exposure pathway and major radionuclides (1996)
Inhabitants of "Digulleville" (1)	14	8	Ingestion ^{85}Kr, ^{14}C, ^{129}I, ^{36}Cl
Fishermen of "Goury" (2)	41	5	Ingestion ^{14}C, ^{129}I, ^{85}Kr, ^{106}Ru, ^{60}Co
Farmers living within an aera situated at less than 1500 m from the gaseous discharge point source	38	24	Ingestion ^{14}C, ^{129}I, ^{85}Kr
Fishermen "zone des Huquets"	226	20	Ingestion ^{14}C, ^{106}Ru, ^{129}I, ^{60}Co
Farmers of "Pont-Durand"	53	59	Ingestion ^{129}I, ^{14}C, ^{85}Kr
"Mean adult" of the La Hague County	18	5	Ingestion ^{85}Kr, ^{14}C, ^{129}I

(1) These two reference groups have been chosen by COGEMA, they have been described in the public inquiry report, February 2000.

(2) During the 30 years of operation (1966-1996), marine discharges from La Hague were at a maximum in 1985 and atmospheric releases were at a maximum in 1996.

Source: [GRNC, GT-4, 1999, Annex 12]

ANNEX 23 OECD Nuclear Energy Agency Dose Estimates for the Public and Workers for the Reprocessing and Direct Disposal Options

Table 39 Comparison of the Collective Dose to General Public and Workers in Two Options for Spent Fuel Management – Direct Disposal (Once-Through Cycle) a nd Reprocessing

	Public (generic calculations) Collective dose truncated at 500 years (man.Sv/GW.a)		**Workers (operational data)** Annual collective dose (man.Sv/GW.a)	
Fuel cycle stage	Once-through	Reprocessing	Once-through	Reprocessing
Mining and milling	1.0	0.8	0.02-0.18	0.016-0.14
Fuel conversion and enrichment	0.0009		0.008-0.02	0.006-0.016
Fuel fabrication			0.007	0.094
Power generation	0.6	0.6	1.0-2.7	
Reprocessing, vitrification	Not applicable	1.2	Not applicable	0.014
Transportation	Trivial	Trivial	0.005-0.02	0.005-0.03
Disposal	0	0	Trivial	Trivial
Total	**1.6**	**2.6**	**1.04 - 2.93**	**1.14 - 2.99**

Source : [NEA, 2000]

The collective dose is the sum of the doses to all the individuals in an exposed population (in this study, collective doses are summed to a limited period of 500 years). The unit is the man.sievert (man.Sv). Releases and discharges into the marine environment and into the atmosphere have been normalised to one unit of electricity produced (1 Gigawatt.year), and the collective dose has consequently been normalised as well (manSv/GW.a).

The number of delayed radiation-induced health effects (fatal cancers) is in proportion to the collective dose (as notified in the International Commission on Radiological Protection Recommendations).

ANNEX 24 Assessment of the "non-attributed" activity of Iodine-129 at La Hague

Differences between the theoretical quantities of iodine-129 (^{129}I) brought into the La Hague plant (in spent fuel) and iodine-129 discharges should be small.

The theoretical quantities of iodine-129 in spent fuel have been calculated according to two codes, COGEMA 1998 and UNSCEAR 1993. Potentiel iodine-129 activity is calculated following the formula:

A (GBq/y) = (Reprocessed quantity in t / 25) x (Fuel burnup in MWdays per t / 33,000) x 0,925 GWe x K

where K is the conversion factor used by the code. The codes use significantly different values for K, i.e. K = 30 GBq/GWe from COGEMA; K = 42 GBq/GWe from UNSCEAR (one can also find in a 1980 code from NEA/OCDE the value K = 50 GBq/GWe). There is no direct explanation to such a difference.

The gap is expressed in GBq per year and in percent of theoretical activity in spent fuel. The calculation does not take into account the quantities of iodine-129 that are held in the filters, as they are supposed to be negligeable. Half of the quantity theoretically introduced into the La Hague facilities in 1991 remains "unattributed" following the UNSCEAR code. For 11 years of operation, 5,213 GBq, or 30.3% of the treated iodine, remains "unattributed" with the same code. With the COGEMA code, 7% is unanswered for.

Table 40 Evaluation of "Unattributed" Iodine-129 Activity at La Hague (1989-1999) using COGEMA and UNSCEAR Codes

Year	Reprocessed quantities (t)	Fuel burnup (MW.d/t)	**[A]** Potential ^{129}I activity		**[B]** Liquid releases	**[C]** Gaseous releases	***Gap:* A - (B + C)**	
			COG 98	UNS 93			COG 98	UNS 93
1989	460.6	25,623	397	556	262	27	108 (27%)	267 (48%)
1990	525.7	25,121	444	622	327	18	99 (22%)	277 (45%)
1991	662.5	30,509	680	952	455	23	202 (30%)	474 (50%)
1992	668.1	26,790	602	843	479	11	112 (19%)	353 (42%)
1993	955.2	24,657	792	1,109	646	10	136 (17%)	453 (41%)
1994	1.276.3	29,437	1,264	1,769	1,120	21	123 (10%)	628 (36%)
1995	1.558.7	30,519	1,600	2,240	1,530	32	38 (2%)	678 (30%)
1996	1.680.9	28,102	1,589	2,224	1,690	38	-139	496 (22%)
1997	1.669.9	*30,000*	1,685	2,359	1,630	17	38 (2%)	712 (30%)
1998	1.628.7	*30,000*	1,644	2,301	1,780	16	-152	505 (22%)
1999	1.562.0	*30,000*	1,576	2,207	1,830	7	-261	370 (17%)
Total			**12,273**	**17,182**	**11,749**	**220**	**856** (1)	**5,213**

(1) This total does not include any negative figure for logical reasons (i.e. unaccounted material cannot be negative)

ANNEX 25 Letter to Annie Sugier, President of the Radio-Ecological Group North-Cotentin, about Iodine-129

Madame Annie SUGIER

Directrice déléguée à la protection de l'IPSN
Présidente du Groupe Radioécologie Nord-Cotentin
Institut de Protection et de Sûreté Nucléaire
BP6
92225 FONTENAY-AUX-ROSES Cédex

Paris, le 9 mai 2001

Madame la Présidente,

Tout d'abord, je vous remercie vivement de l'intérêt que vous portez et du temps que vous avez consacré à la discussion de questions liées à l'étude que nous menons pour le programme STOA (Scientific and Technological Option Assessment) du Parlement Européen sur l'impact des usines de Sellafield et La Hague.

Si la réunion du 27 avril 2001 dans les locaux de l'IPSN n'a pas permis de conclure sur un certain nombre de questions, elle a clarifié l'intérêt d'évaluer plus à fond certaines incertitudes inhérentes à l'état des connaissances sur l'impact des rejets des usines de retraitement. WISE-Paris a notamment soulevé un certain nombre de problèmes liés aux incertitudes sur le bilan en Iode 129 et l'évaluation de l'impact des émissions, sans pour autant pouvoir exclure des problèmes similaires pour d'autres radionucléides rejetés. Vu la gravité potentielle de l'impact sur l'homme et l'environnement des ces émissions nous estimons urgent la mise en place d'une procédure permettant d'apporter des réponses satisfaisantes à ces interrogations.

Nous sommes très conscients du fait que l'analyse de ces questions prenne largement plus de temps que disponible dans le cadre de notre mission pour le Parlement Européen. C'est pourquoi nous reprenons avec grand intérêt votre suggestion de l'établissement d'un groupe de travail avec l'IPSN (et peut-être d'autres organismes ou experts indépendants) focalisé sur des questions précises à l'instar du groupe de travail constitué suite aux interrogations formulées par André Guillemette en octobre 1999. Nous sommes prêts à participer à un tel groupe de travail, selon des modalités qui restent à définir ensemble.

Veuillez trouver ci-dessous un résumé des questions qui pourraient faire l'objet d'un examen par un groupe de travail :

1) Incertitudes sur le bilan en Iode 129 :

Ce point fondamental a été mis en évidence par le GT 1 du Groupe Radioécologie Nord-Cotentin, notamment dans la figure 11c (page 144 du rapport) qui établit sur la période 1966-1976 la « comparaison de l'activité de l'iode 129 dans les rejets gazeux avec la différence d'activité entre le combustible et les rejets liquides ». Cette figure établit en particulier à partir de 1977 une comparaison entre l'activité théorique (combustible moins rejets liquides) et mesurée des rejets gazeux, et démontre des écarts très importants, notamment pour la première moitié de la décennie 1990-2000.

Ce résultat important ne fait malheureusement l'objet d'aucune explication ni d'aucun commentaire du GT1.

Nous avons reconstitué, à partir des tonnages et des taux de combustion moyens des combustibles retraités, les activités théoriques en iode 129 dans le combustible pour les années 1989 à 1999, en utilisant différents coefficients de conversion (GBq d'iode 129 par GW électrique). Les chiffres obtenus ont été comparés à la

chronique des rejets liquides et gazeux mesurés pour la même période. Les résultats sont présentés dans le tableau 1 en annexe.

On constate des écarts très importants entre l'activité théorique et l'activité rejetée mesurée. Si l'on utilise la valeur du coefficient retenue par COGEMA en 1998 (30 GBq/GWé), cet écart peut se produire dans les 2 sens : ainsi, on trouve 202 GBq d'iode 129 non attribués pour 1991, mais inversement les rejets mesurés dépassent de 261 GBq l'activité théorique pour 1999. Toutefois, ce coefficient est inférieur à d'autres valeurs utilisées par l'UNSCEAR en 1993 et l'AEN en 1980 (respectivement 42 et 50 GBq/GWé). Si ces valeurs doivent être retenues, les évaluations de l'activité non attribuée (c'est-à-dire non retrouvée dans les mesures de rejets) varient entre 267 et 1.161 GBq par an.

Selon ces calculs, l'activité non attribuée apparaît certaines années égale ou supérieure à la totalité de l'activité mesurée dans les rejets (on trouve ainsi, avec le coefficient UNSCEAR, 474 GBq non attribués contre 478 GBq mesurés dans les rejets pour l'année 1991). Les évaluations du bilan en iode 129 des usines de retraitement à La Hague semblent donc soumises à une très grande incertitude.

Sur le même sujet du bilan en iode, j'attire également votre attention sur des calculs effectués par l'Institut de Protection et de Sûreté Nucléaire en 1993 dans un rapport sur la sûreté de l'usine UP3-A. Ce document, dont WISE-Paris n'a qu'une connaissance partielle, semble contenir des évaluations du bilan en iode 129 de 1990 au premier semestre 1993 marquées par de multiples erreurs ou approximations. En particulier, le bilan semble basé sur une valeur plus faible de l'activité massique de l'iode 129 que la valeur usuelle (5,2 MBq/g au lieu de 6,5 Bq/g).

Les résultats obtenus en remplaçant la première valeur par la seconde sont rassemblés dans le tableau 2 en annexe : les calculs de l'IPSN mettaient en évidence des écarts inférieurs à 5 %, sauf pour 1990 où l'écart atteint 43 % ; après correction de l'activité massique, l'activité non attribuée est toujours supérieure à 20 % de l'activité théorique, et atteint même 54 % pour l'année 1990.

Cette analyse, si elle est confirmée, renforce le sentiment qu'il existe dans les bilans actuels une très grande incertitude sur l'iode 129, résultant en quantités significatives d'activité non attribuée.

2) Les impacts potentiels de l'activité non attribuée en Iode129 :

Les quantités en iode correspondant à cette activité non attribuée peuvent être retenues dans les installations, « piégées » dans les déchets ou rejetées dans l'environnement. Ces quantités paraissent en tous cas suffisamment importantes pour que l'on s'interroge sur leur impact potentiel en termes de doses à la population. On a ainsi cherché, par des calculs simples, à évaluer les ordres de grandeur de l'impact éventuel lié à l'activité non attribuée en iode 129. On a développé ces calculs pour :

- la dose moyenne à la population du canton due à l'exposition interne par inhalation (rejets gazeux),
- la dose moyenne à la population du canton due à l'ingestion d'aliments marins (rejets liquides),
- la dose collective globale à long terme.

Dans l'ensemble de ces calculs, on a retenu systématiquement l'hypothèse la plus pénalisante, afin de mesurer le risque d'erreur maximal lié à l'incertitude sur le bilan en iode 129. Ainsi, on suppose lorsqu'on évalue la dose liée aux rejets gazeux par exemple que l'ensemble de l'activité non attribuée en iode 129 est rejetée sous cette forme, ce qui est une hypothèse vraisemblablement maximaliste. De même on suppose que la totalité se trouve dans les rejets liquides lorsqu'on calcule la dose par ingestion d'aliments marins.

• *Exposition interne par inhalation :*

À partir de la formule 1 présentée en annexe, on peut calculer la dose induite pour la population du canton par l'iode 129, selon la voie aérienne par inhalation directe. Dans le cas où l'ensemble de l'iode 129 correspondant à l'activité non attribuée se retrouvait dans cette voie, on obtient ainsi une dose de 33 mSv pour l'ensemble de la période 1989-1999 (à partir des résultats du tableau 1, colonne AEN80). Cette dose correspond à une moyenne de 3 mSv/an pour l'ensemble de la population du canton, ou encore de 0,4 microSv pour un individu en un an.

La dose potentielle peut atteindre, pour un habitant de Pont-Durand (point où le coefficient de transfert atmosphérique est le plus élevé du canton, avec un maximum de $3{,}42\ 10^{-7}\ s/m^3$, contre $5{,}36\ 10^{-8}\ s/m^3$ en

moyenne) des valeurs 6 fois plus élevées. Ce chiffre se rapproche de la dose efficace totale calculée par le GT 4 du GRNC pour un individu « moyen » du canton de Beaumont-Hague, qui s'élève à 5 microSv par an.

• *Exposition interne par ingestion :*

De la même manière, à partir de la formule 2 présentée en annexe, on calcule la dose induite pour un individu ou un groupe par l'iode 129, selon la voie alimentaire. Dans le cas où l'ensemble de l'iode 129 correspondant à l'activité non attribué se trouverait dans les rejets liquides, celle-ci représenterait par exemple pour le groupe de référence des pêcheurs de Goury une dose individuelle de 31,6 microSv pour la période 1989-1999. Cette dose correspond en moyenne à 2,9 microSv par individu chaque année.

• *Dose collective globale :*

À partir des modèles de dispersion globale utilisés pour calculer la dose collective à très long terme (10.000 ans, 100.000 ans ou pour un temps infini) pour l'ensemble de la population mondiale, on peut comparer la dose collective maximale que peut représenter l'activité non attribuée en iode 129 à la dose collective estimée à partir des rejets mesurés.

Les résultats sont résumés au tableau 3 pour deux modèles développés par l'AIEA en 1985 et par l'UNSCEAR en 1993. Si le modèle UNSCEAR retient un facteur de dose très faible pour l'iode 129, le modèle AIEA retient des facteurs plusieurs centaines de fois plus élevés qui conduisent à des valeurs très fortes : ainsi, dans l'hypothèse la plus pénalisante (toute l'activité non attribuée est rejetée sous forme gazeuse), l'activité non attribuée représente 1.817 h.Sv, alors que l'ensemble des principaux rejets déclarés (tritium, iode 129, carbone 14 et krypton 85) ne représente que 4 fois plus avec 7.265 h.Sv.

En vous remerciant par avance pour l'intérêt que vous voulez bien porter à ces questions, veuillez accepter, Madame la Présidente, l'expression de mes salutations cordiales.

Mycle SCHNEIDER,
Directeur de WISE-Paris.

Annexes à la Lettre à Annie Sugier, Présidente du GRNC :

Tableau 1. Estimation de l'activité en iode 129 dans le combustible retraité[1] et calcul de l'activité non attribuée[2] en iode 129 dans les installations de COGEMA-La Hague, 1989-1999 (en GBq)

Année	Tonnage retraité (t)	Tc (MW.j/t)	(A) Potentiel ^{129}I combustible			(B) Rejets liquides	(C) Rejets gazeux	Activité non attribuée (A-B-C)		
			AEN80	UN93	COG98			AEN80	UN93	COG98
1989	460,6	25.623	662	556	397	262	27	373	267	108
1990	525,7	25.121	740	622	444	327	18	395	277	99
1991	662,5	30.509	1.133	952	680	455	23	655	474	202
1992	668,1	26.790	1.003	843	602	479	11	513	353	112
1993	955,2	24.657	1.320	1.109	792	646	10	664	453	136
1994	1.276,3	29.437	2.106	1.769	1.264	1.120	21	965	628	123
1995	1.558,7	30.519	2.667	2.240	1.600	1.530	32	1.105	678	38
1996	1.680,9	28.102	2.648	2.224	1.589	1.690	38	920	496	-139
1997	1.669,9	*30.000*	2.808	2.359	1.685	1.630	17	1.161	712	38
1998	1.628,7	*30.000*	2.739	2.301	1.644	1.780	16	943	505	-152
1999	1.562,0	*30.000*	2.627	2.207	1.576	1.830	7	790	370	-261

1. Le potentiel d'activité en iode 129 dans le combustible retraité (A) est calculé à partir du tonnage retraité TR et du taux de combustion moyen Tc selon la formule : A (en GBq/an) = (TR/25) x (Tc/33000) x 0,925 x K.
Cette formule correspond à l'hypothèse selon laquelle 25 tonnes de combustible usé à 33 GW.j/t alimentent 0,925 GWélec par an.
K exprime le ratio GBq/GWélectrique utilisé pour l'iode 129, qui dépend du code de calcul utilisé pour évaluer le contenu du combustible irradié. On a utilisé ici trois coefficients :

- AEN80 : 50 GBq/GWé, utilisé par l'Agence de l'Énergie Nucléaire (OCDE) en 1980 ;
- UN93 : 42 GBq/GWé, utilisé par l'UNSCEAR (Nations-Unies) en 1993 ;
- COG98 : 30 GBq/GWé, utilisé par COGEMA en 1998, et qui correspond à une hypothèse de facteur de charge = 60 % par rapport à un facteur de charge = 100 % pour l'AEN80.

2. L'activité non attribuée en iode 129 est calculée en retranchant de l'activité théorique dans le combustible (A) les activités en iode 129 mesurées dans les rejets liquides (B) et gazeux (C).

Tableau 2. Bilan en iode 129 calculé par l'IPSN et « corrigé » pour l'usine UP3-A de La Hague et calcul de l'activité non attribuée en iode 129 correspondante, de 1990 au 1er semestre 1993 (en MBq)

Année	Activité théorique[1]		Activité des différents rejets					Activité non attribuée[4]	
	IPSN	Corr.	Rejets en mer	Transfert à STE	Filtres	Résidus[3] dissolution	Rejets gazeux	IPSN	Corr.
1990	190.632	238.290	101.000	3.484	450	2.288	1.107	82.303 (43,2 %)	129.961 (54,5 %)
1991	343.138	428.922	321.900	2.722	860	4.118	4.217	9.321 (2,7 %)	95.105 (22,2 %)
1992	432.500	540.625	408.900	3.585	1.667	5.190	5.486	7.672 (1,8 %)	115.797 (21,4 %)
1993[2]	379.000	473.750	351.600	2.876	1.102	4.548	3.697	15.177 (4,0 %)	109.927 (23,2 %)

1. L'activité théorique est calculée selon la formule : activité = activité massique x tonnage retraité x concentration.
On retient une valeur de 188 g/t pour la concentration en iode 129, valeur moyenne utilisée par l'IPSN pour les années 1992-1993 (on trouve dans la littérature des valeurs variant au moins de 170 à 230 g/t).
La colonne IPSN indique l'activité théorique obtenue avec la valeur de 5,2 MBq/g utilisée par l'IPSN dans son rapport de 1993, la colonne Corr. indique l'activité théorique corrigée avec la valeur usuelle de 6,5 MBq/g.

2. Bilan calculé pour le premier semestre de l'année 1993 seulement.

3. Les résidus de la ligne de dissolution représentent 1,2 % du total.

4. L'activité non attribuée en iode 129 est la différence entre l'activité théorique et la somme des activités des différents rejets.

Formule 1. Calcul de la dose collective pour la population du canton par inhalation d'iode 129 présent dans les rejets gazeux des usines de La Hague

Dose = pop. canton x débit rejets x débit respiratoire x CTA_{dp} x FCD_{inh}

où :
- *pop. canton* est la population du canton (soit 7.572 personnes),
- *débit rejets* est le débit d'activité en iode en sortie de cheminée (en Bq/s),
- *débit respiratoire* est de 8.400 m^3/an pour un adulte,
- CTA_{dp} est le coefficient de transfert atmosphérique « doublement pondéré » (max. 5,36 10^{-8} s/m^3),
- FCD_{inh} est le facteur de conversion de dose pour l'iode 129, dans le cas de l'inhalation (soit 3,6 10^{-8} Sv/Bq, selon la Directive Euratom 96/29).

Formule 2. Calcul de la dose collective pour la population du canton par ingestion dans les aliments marins d'iode 129 présent dans les rejets liquides des usines de La Hague

Dose = ? $_i$ [Quantité A_i x Activité A_i] x FCD_{ing}

où :
- les A_i sont les aliments marins, avec :

Quantité A_i est la quantité absorbée par la population considérée (en kg/an),
Activité A_i = débit rejets x FD x fraction en suspension x FC_i, (en Bq/kg frais),
avec :
- *débit rejets* est le débit d'activité en iode en sortie de conduite (en TBq/an),
- *FD* est le facteur de dilution (3,42 Bq/m^3 par TBq/an à l'anse des Huquets),
- *fraction en suspension* (1 – taux de sédimentation) est supposée quasi égale à 1,
- FC_i est le facteur de concentration de l'espèce marine donnant A_i (en l/kg),

- FCD_{ing} est le facteur de conversion de dose pour l'iode 129, dans le cas de l'ingestion (soit 1,1 10^{-7} Sv/Bq, selon la Directive Euratom 96/29).

Tableau 3. Dose collective induite par les rejets de tritium, iode 129, carbone 14 et krypton 85 des usines de La Hague pour l'année 1999, et estimation de la dose collective potentielle liée à l'activité non attribuée en iode 129 pour la même année

		Rejets[1] 1999	h.Sv/TBq[2]		h.Sv	
		La Hague (TBq)	AIEA 85	UNSCEAR 93	AIEA 85	UNSCEAR 93
Tritium	gaz	80	0,00942	0,00120	0,75	0,096
	liquide	12.900	0,000045	0,00012	0,58	1,548
Iode 129	gaz	0,0074	2.300	4	17,02	0,0296
	liquide	1,83	1.700	4	3.111,00	7,32
Carbone 14	gaz	19	142	85	4.108,06	1.615
	liquide	9,93		85		844,05
Krypton 85	gaz	30.000	0,000093	0,0002	27,90	60
	liquide	-	?	?	-	-
Total (1999)					**7.265,31**	**2.528,04**
Iode 129 non attribué (1999, AEN[3])	gaz ou liquide	0,79 ou 0,79	2.300 1.700	4 4	**1.817** ou **1.343**	**3,16** ou **3,16**

1. Données COGEMA.

2. Les facteurs de dose sont tirés des modèles de dispersion globale suivants :

- AIEA 85 : modèle développé par l'Agence Internationale pour l'Énergie Atomique en 1985 (Technical reports Series n° 250), repris par le CEPN pour les études préparatoires ExternE en 1995. Ce modèle prend en compte un e durée de 100.000 ans et une population de 10 milliards d'individus ;
- UNSCEAR 93 : modèle développé par l'UNSCEAR en 1993 (Report to the General Assembly) pour une durée de 100.000 ans et une population de 10 milliards d'individus (5 milliards pour le tritium et le krypton).

3. Valeur de l'activité non attribuée en iode 129 pour l'année 1999 selon le code AEN80 (cf. tableau 1).

ANNEX 26 Separation, Re-Use and Exportation of Plutonium in France

Table 41 Separation, Use or Exportation of Plutonium, France

	Quantities as of the end of 1998 (t)
Separated Plutonium	
UNGG fuel (reprocessed until 1989)	17.3
UNGG fuel (reprocessed from 1990)	5.5
UOX fuel (reprocessed until 1989)	26.5
UOX fuel (reprocessed from 1990)	102.9
RNR fuel (reprocessed until 1989)	5.7
RNR fuel (reprocessed from 1990)	0.2
MOX fuel (reprocessed from 1990)	0.5
[A] Total separated	***158.6***
Re-use or exportation of Plutonium	
Use in RNR fuel	18.1
Use in MOX fuel	24.1
Sent to foreign country/client (others than Belgonucléaire)	25.9
Sent to Belgonucléaire	14.6
[B] Total re-used or exported	***82.7***
Plutonium stock in France [A - B]	**75.9**

Source: WISE-Paris, 2000

Table 42 Separation and Re-Use of French Plutonium

	Plutonium quantities as of the end of 1998 (t)	
Origin / Use of Plutonium	**Separated Plutonium**	**Plutonium Re-Used**
UNGG Fuel	55,6	–
UOX Fuel	22,7	–
RNR Fuel	5,9	17,0
MOX Fuel	0,2	22,9
Military	?	2,0
Total	**84,4**	**41,9**

Source: WISE-Paris, 2000

ANNEX 27 Material and Economic Balances over the French Reactor Lifetime - Direct Disposal vs. Reprocessing

Table 43 Material and Economic Balances Associated to the French Nuclear Reactors, 1977-2049 (hypothesis of 45 years average lifetime)

Hypothesis on Reprocessing	**Stops** in 2010	**Continued** Partial (60-70% of spent fuel)	**Continued** Total (100% of spent fuel)	**None** (over the whole period)
Generated electricity (TWh)	20,238	20,238	20,238	20,238
Material balances				
Natural uranium (kt)	460	447	437	475
Reprocessed UOX (kt)	15.0	26.2	36.1	0.0
Separated re-used Pu (t)	146	275	387	0
Irradiated UOX to Store (kt)	41.0	28.6	17.6	58.3
Irradiated MOX to Store (kt)	2.0	3.5	4.8	0.0
Final content in Pu (4) (t)	602	555	514	667
MLW (m^3)	31,786	34,825	38,091	20,000
from reactors' operation	20,000	20,000	20,000	20,000
from reprocessing	11,786	14,825	18,091	0
HLW (m^3)	1,601	3,325	4,808	0
Economic balance				
Capital investment (3)	682	682	682	652
Operation	1,297	1,297	1,297	1,297
Fuel Cycle	909	931	948	814
Cycle front end	602	589	578	611
Cycle back end	195	232	263	86
End of cycle	112	110	107	116
Total of expenses (GF)	**2,888**	**2,910**	**2,927**	**2,763**
Cost per kWh (1) (ctsF)	**14.27**	**14.38**	**14.46**	**13.65**
Capital investment	3.36	3.36	3.36	3.22
Operation	6.41	6.41	6.41	6.41
Fuel Cycle	4.49	4.60	4.68	4.02
Cycle front end	2.97	2.91	2.86	3.01
Cycle back end	0.96	1.15	1.29	0.42
End of cycle	0.55	0.54	0.53	0.57

(1) Constant French Francs, 1999 value – These levelised costs are not discounted; they are derived from the global expenses over the reactors' fleet operating lifetime.

(2) "Retrospective" scenario, where France would have chosen the direct disposal option for its spent fuel management from the beginning in 1977.

(3) The difference in the investment line between the three scenarios with reprocessing and the one without corresponds to 30 GF additional expenses in R&D for fuel cycle back-end dedicated to reprocessing.

(4) Plutonium (plus americium) content in the stocks of spent UOX and MOX that are eventually not reprocessed, thus in the final storage.

Source: [Charpin et al, 2000]

ANNEX 28 Dry Storage Technologies

The world's first dry store for spent fuel was constructed in 1970 in north Wales in the UK, as an integral part of the Wylfa reactor, This was built as a buffer store for spent Magnox fuel prior to its removal to Sellafield for reprocessing. The store originally had a capacity of 250 tonnes, later expanded to 950 tonnes. In the US, High Temperature Gas Reactor fuel has been stored in dry wells at the Idaho National Engineering Laboratory since 1971. In Manitoba, Canada, fuel from a PWHR demonstration reactor has been stored in sealed concrete storage casks since 1975. After the mid 1970s, interest in dry stores declinned for a period mainly because of the adoption of inexpensive reracking and double-decking technologies at fuel storage ponds.

Since the early 1990s, interest in dry storage has grown. Dry stores are presently being commissioned or are under construction in Argentina, Belgium, Canada, the Czech Republic, Germany, Hungary, Japan, South Korea, Lithuania, Russia, Ukraine and the US [IAEA, 1996; 1999]. In 1992, Scottish Nuclear, in evidence to the 1992/3 public inquiry into its dry store plans, added Mexico, Italy, India, South Africa, and Taiwan to this list [Hickman, 1993]. Currently about 14% of stored fuel throughout the world is kept in the dry form [IAEA, 1999].

(a) Descriptions of Dry Stores

The distinctive characteristic of dry storage systems is their passive cooling by radiation and air convection. Convection results from the natural thermo-syphon effect of hot spent fuel which ranges in temperature from ~200º to ~360º C. Unlike wet stores, dry stores require virtually no electrical, water, or maintenance inputs, apart from that required for monitoring and surveillance. This results in enhanced reliability and safe operational running for long periods. The nominal life of the former planned Scottish Nuclear dry store in the UK was 100 years, including a 35 year loading period, 50 year storage period and 15 year period for fuel unloading and encapsulation, prior to disposal [Ealing, 1993]. It is expected that dry stores may be able to operate for periods even greater than 100 years [Schneider and Mitchell, 1992b].

A second important characteristic of dry storage systems is their heavy radiation shielding. Spent fuel, even after 10 years' preliminary cooling in ponds, remains highly radioactive; radiation dose rates from unshielded PWR canisters range from 10 to 100 Gy per hour. Dry stores are therefore exercises in heavy engineering involving massive shielding, commonly 60 to 100 cm of heavy density concrete, ductile iron, steel or steel/lead combinations. This reduces surface dose rates of shielded casks to between 200 and 800 µGy per hour.

Dry stores have been in operation since 1970 with relatively few reports of accidents or failure. In 1990, a leak from a flat roof at the UK Wylfa dry store permitted rainwater ingress over a lengthy period. Failure was primarily due to poor building standards (i.e. poor drainage), but the breach was exacerbated by two other factors. First, as the original plans did not envisage fuel corrosion, fuel was not encapsulated in a stainless steel envelope prior to storage and not backfilled with inert gas[67]. Second, the original plans did not foresee that such water-induced corrosion would be accelerated by salt-laden sea air used for cooling, as Wylfa is adjacent to the sea. Modern dry storage plants avoid these problems.

In May 1996, a fire occurred inside a BNFL Corporation VSC-24 cask at Point Beach in Wisconsin, US, during remote welding of the cask lid [NuclearFuel, 1996]. This was due to H_2 gas released from interaction between the zinc coating of the inner container and borated water adhering from wet storage. The US NRC has issued guidance to avoid this problem.in future.

It is necessary to store discharged fuel in cooling ponds to permit nuclide decay before the fuel can be transferred to dry storage. The required duration of the initial cooling period depends on fuel burnup and the heat-handling capacity of the store. For high burnup (>40,000 MWday/tonne) LWR fuel, about 3 years' cooling is required before it may be placed in a vault, and 10 years' cooling before it may be placed in a cask, as casks have much smaller heat-handling capacities than vaults. In all cases, spent fuel assemblies are first dried, in some cases dismantled and reconfigured, sealed within stainless steel canisters, and placed in

[67] As a result, all fuel in current vault systems is encapsulated

the outer cask or vault. Casks or modules are placed on concrete pads in the open air or within hangar-type buildings..

(b) Functions and Regulatory Criteria of Storage

The main functions of spent fuel storage systems are heat removal, subcriticality, and radiation shielding. Accordingly, the key criteria for many national regulators [Ealing, 1993; IAEA, 1994] are, in order of importance

- low temperature of stored fuel,
- subcriticality,
- assurance of heat removal,
- low doses to operators and public,
- environmental protection,
- low volume of waste produced,
- physical protection,
- safeguards against diversion, and
- storage not to prejudice final disposal route.

As of 1994, there were no published UK regulatory criteria for the storage and disposal of spent fuel or vitrified HLW [Griffin, 1994], and it would appear that the same is the case for French spent fuel.

Criticality is an important consideration. Fuel in dry stores which is kept in the same geometrical configuration as in wet stores is inherently subcritical [Pacific-Sierra, 1991], due to the absence of moderating water. At least in theory, no burnup credit is allowed by US regulators [NRC, 1996] in deciding criticality criteria, i.e., the geometric configuration of spent fuel in dry storage must be the same as that for fresh fuel. This means that, although spent fuel contains lower concentrations of fissile isotopes than fresh fuel, US spent fuel may not be consolidated to save space in dry storage containers. Regulators in other countries allow burnup credit however.

Another prime consideration for most nuclear regulators is that spent fuel should be maintained in the best possible condition, in order to facilitate retrieval and final disposal in the future [Carter and Bower, 1995]. This requires fuel to be kept at as low a temperature as possible. Fuel temperatures are important as most mechanisms promoting the degradation of fuel cladding are temperature dependent [Manektela, 1993]. In Hungary, the maximum allowed temperature is 250°C for Russian VVER fuel. In the US and Germany, which use GE/Siemens BWR or Westinghouse PWR fuels, higher maximum temperatures of 340° to 360°C [NRC, 1996] are allowed, due to the higher resistance of zirconium-clad fuels to oxidation [Pacific-Sierra, 1991]. In practice, temperature control is the main operating criterion of dry stores.

(c) Performance of Fuel Cladding in Dry Sto res

The ***performance of fuel cladding*** in dry stores is an important consideration. The cladding integrity of LWR fuel is not affected in wet storage because water temperatures of ~50°C are too low for significant fuel oxidation [Gilbert *et al*, 1990]. Indeed, most countries store defective oxide fuel in the same conditions in pools as intact fuel [IAEA, 1987]. The much higher temperatures (200° to 370°C) in dry stores require that considerable attention be paid to cladding corrosion in dry stores. Therefore the main technical concern with dry storage is the degradation of fuel cladding over time. Degraded cladding may lead to accelerated oxidation of UO_2 in oxide fuel to the less dense U_3O_8 which causes fuel rods to split, and can result in possible serious rod damage.

To ensure absence of cladding degradation and ease of retrieval, dry storage R&D has focused on potential degradation mechanisms in spent fuel cladding in order to determine maximum permissible temperatures and time lengths of spent fuel in storage [Manektela, 1993]. Cladding integrity depends on storage conditions, i.e. temperature, presence of oxygen, time stored, and absence of water. The critical factor is temperature: see Table 45 in ***Annex 29*** for maximum cladding temperatures in various cask types at their maximum heat capacities.

The US Nuclear Regulatory Commission limits the maximum permissible LWR fuel temperature for dry storage purposes to 360 °C to 370°C [Schneider and Mitchell, 1992a] depending on fuel type and burnup. In practice, this means that normal burnup PWR fuel must be cooled in ponds for 5 years, and higher burnup

fuel cooled for up to 10 years before transfer to dry stores. MOX fuel would have to be stored for at least 15 years due to its much higher radioactivity upon exit.

These storage temperatures are close to the normal PWR operating temperatures of 370°-380°C. Gilbert *et al* [1990] cite studies indicating that LWR spent fuel is expected to retain its integrity in inert gas for greater than 50 and up to 100 years. Technical projections using Arrhenius plots for UO_2 oxidation in CANDU fuel predict spent fuel integrity for between 100 to 1,000 years [Stevens-Guille, 1994].

Nuclear regulators and/or nuclear industry engineers from different countries have adopted different rankings for the licensing criteria of dry storage systems. For example, in Germany, greater weight is accorded to meeting the requirements of stringent transport regulations and to physical protection against external incidents, including aircraft crash, gas cloud explosion, fire, temporary burial, earthquake, transport crashes, and drop [Weh, 1993]. German regulators also prohibit ventilated casks due to concerns over genetic mutations to insects, bacteria and viruses which may enter ventilation spaces [Janberg, 1994]. For these reasons, German CASTOR casks are built to resist physical insult and are sealed i.e. unventilated. Cooling is by direct radiation and air convection of outer surfaces, and not additionally by inner air convection. The result is that unventilated German casks for LWR fuels are made from metal rather than concrete, as metals have higher heat conductivities than concrete. This results, inter alia, in unventilated German metal casks being more expensive than ventilated concrete casks.

Overall, national regulatory and licence requirements have a strong influence on, and indeed limit utility choices between dry store systems. Different countries have emphasised different criteria, placing national restrictions on storage choices. The process of drawing up regulatory or licence conditions for dry fuel storage has not been completed in many countries, and has not been started in France.

(d) Types of Dry Stores

Three main types of dry storage are currently in use, as follows

a) vaults or silos, i.e. large ventilated buildings, capacity ~600 to ~2,000 tonnes;
b) metal casks, i.e. unventilated metal cylinders, capacity ~10 to ~17 tonnes; and
c) ventilated concrete casks or modules holding ~5 to ~15 tonnes.

• Vaults

According to Scottish Nuclear's former plans for dry storage [Scottish Nuclear, 1992a], the maximum heat load in each 60 tonne vault was 1 MW, with 20 vaults planned. This is an extremely large heat output, and indicates the scale of the heat-handling capacities of vaults which are considerably larger than those of casks. Cooling in vaults occurred by natural air convection with temperature differences of about 15°C between ingress and egress air. Airflow rates for vaults are very large and range between 50-80 cubic metres per second [Scottish Nuclear, 1992b].

The Modular Vault Dry Store system in Hungary handles loads of up to 17 kW per tonne of fuel when fully loaded compared with about 1.4 to 2 kW per tonne for concrete casks. Vaults have sufficient heat removal capacity to keep fuel cladding temperatures of 5 year-cooled PWR assemblies below 200°C [Carter and Bower, 1995]. Maximum fuel cladding temperature of Scottish Nuclear's planned store was 250°C [Scottish Nuclear, 1992b]. On the other hand, concrete and metal casks hold their fuel temperatures near the maxima of 360°C to 370°C allowed by the US Nuclear Regulatory Commission [NRC, 1996].

Gamma and neutron shielding is afforded by 60-100 cm concrete walls [Scottish Nuclear, 1992b]. The maximum public dose rate at the perimeter fence 100 metres from the vault was estimated to be 0.8 µSv/hour from the side wall, or 2.1 µSv/year assuming a 30% occupancy rate). A small part of the radiation dose from dry stores to operators and the public was due to skyshine radiation. In addition, doses from gaseous and liquid effluents, mostly from drying operations, were estimated at 2.3 µSv/a, giving a total of about 4 µSv/a [Sumner, 1993]. This is low compared to the ICRP recommended limit to a member of the public of 1,000 µSv/a from all radiological sources.

• Concrete Casks

Maximum heat loads in concrete casks are 22 to 24 kW when fully loaded depending on model [Wisconsin PSC, 1994]. Maximum fuel temperatures are about 360°C, depending on fuel type and burnup. Cooling in concrete casks occurs primarily by air ventilation between inner container and outer concrete shield. The

maximum volume of air flowing through a BNFL VSC-24 cask is 0.38 cubic metres per second or 825 cubic feet per minute. This air is heated 20° to 32°C above ambient temperatures, depending on the ambient temperature. Some cooling is also provided by radiation and air convection from the outer cask surface. Temperatures of the cask surfaces are a few degrees C above ambient temperatures.

Shielding from gamma radiation and neutrons is effected by borated concrete alone, as hydrogen and boron atoms in concrete thermalise neutrons. Maximum calculated dose rates at the side of concrete casks vary from 480 µSv per hour for Vectra Associates' NUHOMS 24P cask to about 600 µSv per hour for BNFL VSC-24 flasks. Maximum calculated dose rates to the public at site boundaries vary with site, ranging between 10 to 60 µSv/a [All data: Wisconsin PSC, 1994].

• ***Metal Casks***

Maximum heat loads in metal casks vary between 17 and 27 kW, depending on model. Cooling in metal casks is afforded solely by radiation and convection from outer finned surfaces: inner cores in metal casks are unventilated. Cask surface temperatures are 10 to 20°C above ambient temperatures. Gamma shielding is afforded by the various metals used including steel, iron, and lead. Hydrogen-rich polyethylene inserts in outer shielding provide neutron shielding. Maximum surface dose rates of metal casks are higher than concrete casks and vary between 800 µSv per hour for Nuclear Assurance Corporation NAC-128 casks to 500 µSv per hour from the German GNS Castor V/21 flask. [All data Wisconsin PSC, 1994].

The main operational difference between the two types of casks is that steel casks have no convection cooling and are hotter to touch.

ANNEX 29 Dry Storage Economics

(a) Comparison of Wet and Dry Stores

Siemens engineers [Peehs and Banck, 1993] have stated that marginal dry store capital costs are considerably lower stored than wet stores, particularly in the case of small stores. In addition, the multiple operating systems (filtration, boration, cooling and chemical buffering), and maintenance requirements of pool storage result in considerably higher operating costs for pools. Bowser *et al* [1994] estimated that the annual running costs of wet ponds to store fuel from the closed Rancho Seco reactor in California to be $10.6 million per year and for dry stores – $2.6 million per year – a four-fold difference.

In most cases, since pool costs have been fully paid for and dry stores have yet to be constructed, a useful comparison is the amortised cost of constructing a dry store plus annual operating costs, compared with the annual operating costs of an existing pool. In the above Rancho Seco study, the costs of constructing a transportation plus dry storage system to store spent fuel were estimated at $12.4 million. The study amortised this figure over a 10-year depreciation period using a 5% interest rate. This, plus annual running costs, resulted in an estimated total annual cost of $4.2 million for dry storage compared with annual operating costs of $10.6 million for wet storage, a 2.5 fold decrease in annual costs. In other words, considerable savings accrued from constructing dry stores and transferring fuel from pools to the dry stores. The Table below compares estimated costs of wet and dry storage systems in more detail.

Table 44 Cost of Wet and Dry Storage Options

Management options for spent LWR fuel	Estimated cost for 500 tonnes of fuel for 20 years	Estimated cost per tonne of fuel over 20 years	Ratio of cost to dry storage cost, operating reactor
Pond storage (1)	$230 million	$460,000	4.6 to 6.7
Dry storage at *closed* reactor (1)	$148 million	$180,000	1.8 to 2.6
Dry storage at *operating* reactor (2)	$34-$50 million	$68,000-$100,000	~1

(1) Estimated from Browser [1994].
(2) Estimated from Supko [1995].

(b) Costs of Dry Stores Types

• Vaults vs Casks

An older study [IAEA,1990] compared the costs of casks and vaults: the main finding is that after about 350 tonnes, the marginal cost of storing fuel was lower in vaults. This represents approximately 14 years' fuel output from a 1,000 MW PWR reactor at 35-40,000 MWdays/tonne. A major difference between vault and cask systems is that vaults provide only storage, whereas casks may also satisfy transport regulations and be suitable for final disposal in a repository, depending upon future regulatory criteria (see ***Annex 28*** for further discussion of the different types). In European practice, vaults will be more cost effective for at-site storage and casks will probably be more cost effective for fuel to be transported to a central site. Castor and NAC casks, for example, are designed for transportation.

• Cost Comparisons of Different Casks

Cost comparisons of cask systems involve uncertainties, as costs may include estimates of transport and encapsulation costs. These require predictions or assumptions of transportation standards, which are likely to be improved over time, and predictions of future repository standards. A further refinement is the choice between steel and concrete casks. The US Electrical Power Research Institute concluded that concrete casks had incremental total system savings of 10% to 20% over metal casks [Lambert *et al*, 1993]. This was primarily due to the less expensive material costs of concrete casks. In terms of immediate storage, i.e. ignoring future transportation and encapsulation stages, Lambert concluded that concrete casks offered utility operators 58% savings over the cost of steel casks. Cask costs account for about two thirds of total storage

costs over a 20 year period [Supko, 1995], with the remaining third due to the construction of drying and loading facilities.

In 1994, the Sacramento Municipal Utility District constructed a dry store for fuel from its closed reactor at Rancho Seco in California. The utility predicted [Bowser *et al*, 1994] annual operating costs for the proposed dry store of $2.6 million, with planning and construction costs of $12.4 million for the transportation and dry storage system. Over a 20 year period, total undiscounted costs would be $64 million, or approximately $280,000 per tonne.

Supko [1995] predicted dry storage costs of an ***operating*** nuclear utility whose storage costs were permitted by its Public Utility Commission as an operating overhead and thus charged to electricity ratepayers [NuclearFuel, 1993a]. As a result, operating and insurance costs were significantly lower than those at a closed site. Estimated representative life-cycle costs over a 20-year period for a 500 tonne dry store were $34 to $50 million, or $68,000 to $100,000 per tonne. These are considerably lower than costs at a closed reactor. In 1994, a US study [Wisconsin PSC, 1994] calculated total costs of casks ranging from $35,000 to $68,000 per tonne, as set out in table below.

Table 45 Comparison of Types of Dry Store Casks

Type	VSC-24	Nuhoms-24P	TN-24	TN-40	NAC-128	Castor V-21
Manufacturer	Sierra Nuclear	Vectra	Trans-nuclear Inc.	Trans-nuclear Inc.	Nuclear Assurance Corp'n	GNS
Country of Manufacture	US	US	Ger-Bel-Neth	Ger-Bel-Neth	US	German
Air Ventilated	Yes	Yes	No	No	No	No
Cask Material	Steel-reinforced Concrete	Steel-reinforced Concrete	Pressure Vessel Steel	Pressure Vessel Steel	Stainless Steel, Lead	Ductile Cast Iron
Max. Number of PWR Assemblies	24	24	24	40	26-31	21-28
Max. Cladding Temperature	364°C	364°C	332°C	332°C	230°C	<250°C
Heat Capacity kW	24	24	24	27	17.4	21
Cost per cask	$300,000	$380,000	$900,000	$700,000	$1,040,000	$800,000
Estimated Total Cost per tonne	$35,000	$38,000	$62,000	$40,000	$68,000	$57,000

Source: [Wisconsin PSC, 1994]

Differences between cask costs are due to the different characteristics required by national regulatory criteria. Casks designed with future transport and/or disposal requirements in mind are more expensive than those designed solely for storage. A major factor is whether casks are cooled by air ventilation or not. Such casks are less expensive than sealed containers, as they dissipate heat by inner convection as well as radiation, thereby eliminating the need for expensive machined metal containers. However such casks are limited in their performance capabilities in that they are generally not able to be used for transport or disposal, and have lower impact capabilities. Nevertheless their high heat-handling capacity combined with low cost are attractive features for US utilities.

Even lower estimated costs of $15,000 to $20,000 per tonne have been cited by Ontario Power Generation [Stevens-Guille and Pare, 1994; Nash, 1997] for its planned 40,000 tonne dry storage facility in Ontario. This will eventually use more than 6,000 unventilated steel and concrete containers. These very low estimated marginal costs are due to a number of factors including

- simple design reflecting straightforward regulatory requirements
- economies of scale from standardised design/production
- avoidance of high capital costs as canisters are constructed when required and stored in the open on a concrete pad,
- access to low cost finance by Government-owned corporation,
- ability to charge costs to electricity tariffs, and

- less shielding and lower heat-handling capacity required for low burnup CANDU fuels (~6,000 MWdays/tonne).

(c) Conclusions

Most (>80%) spent fuel arisings are stored and most countries are moving towards storage as a medium-term strategy for spent fuel. According to the IAEA [1999], new developments in spent fuel management concern storage rather than reprocessing and dry rather than wet storage. For waste management policies, an important issue is the degree to which dry storage may be considered a viable long-term option for managing spent fuel. Dry storage in inert gas presents relatively few theoretical or practical difficulties. The IAEA has concluded after reviewing national experiences of dry storage that it is an acceptable waste management option for the storage of spent fuel for periods of 50 to 100 years [IAEA, 1996]. By this time heat rates have declined by two orders of magnitude. The anticipated longevity of dry stores (50 to 100 years) is expected to exceed that of wet stores [Schneider and Mitchell, 1992a]. It is concluded that passive dry storage systems appear to be an acceptable means of managing spent nuclear fuel in the medium to long term.

When reprocessing and storage are compared, large differences in costs become apparent: the former are clearly greater than the latter. US/Canadian storage systems are even less expensive: US dry storage systems for PWR fuel are estimated to be 8 to 20 times less expensive per tonne than reprocessing. In addition, dry stores are considerably less expensive to construct and to operate than wet stores: annual costs are about a factor of 4 lower.

Environmental and local groups in some countries have not opposed dry storage developments. This was evidenced by the 1987 agreement among major UK environmental groups, supported by over 40 regional and local groups, to a collective strategy of long-term on-site storage. Under this plan, waste would be stored where the waste was generated in facilities designed to optimise monitorability and retrievability [CORE, 1987]. A US research organisation critical to nuclear power concluded that on site dry storage was needed to resolve capacity problems of reactor operators, to reduce the temperature of spent fuel thus reducing degradation risks, and to reduce transportation risks [IEER, 1989]. During the 1992-1994 UK public inquiry into Scottish Nuclear's dry storage plans [Hickman, 1994], no environmental group made representations against the plans.

In France and the UK, the obstacles to the adoption of dry storage technology are the political, industrial and financial interests committed to reprocessing. This results in the philosophical unwillingness of managers within industry and Government to consider the issue of dry storage. Longer term dry storage is apparently not within their frame of reference. The overall conclusion is that, despite the considerable advantages of dry storage over reprocessing, the large resources, political commitments and institutional investments in reprocessing in France and the UK are expected to continue to act to hinder dry storage developments in these countries in the immediate future.

ANNEX 30 Data on Radionuclides

Table 46 Main Radionuclides (1) Period, Radioactivity, Radiotoxicity and Origin

Number	Isotope	Symbol	Period (years, days, hours, seconds)	Radioactivity (2)	Radiotoxicity (3)	Release type
3	Tritium	^{3}H	12.3 y	β pure	low (gr. IV)	liquid + gaseous
14	Carbon-14	^{14}C	5,730 y	β pure	moderate (gr. III)	liquid + gaseous
36	Chlorine-36	^{36}Cl	300,000 y	γ soft	moderate (gr. III)	liquid + gaseous
40	Potassium-40	^{40}K	1.3×10^{9} y	β, γ	low (gr. IV)	liquid
60	Cobalt-60	^{60}Co	5.3 y	β, γ	high (gr. II)	liquid + gaseous
85	Krypton-85	^{85}Kr	10.7 y	β, γ	low (gr. IV)	gaseous
90	Strontium-90	^{90}Sr	28.8 y	β pure	high (gr. II)	liquid + gaseous
95	Zirconium-95	^{95}Zr	64 d	β, γ	high (gr. II)	liquid + gaseous
95	Niobium-95	^{95}Nb	35 d	β, γ	moderate (gr. III)	gaseous
99	Technetium-99	^{99}Tc	214,000 y	β	low (gr. IV)	liquid
103	Ruthenium-103	^{103}Ru	39 d	β, γ	low (gr. IV)	liquid + gaseous
106	Ruthenium-106	^{106}Ru	372 d	β	high (gr. II)	liquid + gaseous
106	Rhodium-106	^{106}Rh	30 s	β, γ	low (gr. IV)	liquid
110	Silver-110	^{110m}Ag	250 d	β, γ	high (gr. II)	liquid
125	Antimony-125	^{125}Sb	1,010 d	β, γ	moderate (gr. III)	liquid + gaseous
129	Iodine-129	^{129}I	1.57×10^{7} y	β, γ soft	low (gr. IV)	liquid + gaseous
131	Iodine-131	^{131}I	8 d	β, γ hard	high (gr. II)	liquid + gaseous
133	Iodine-133	^{133}I	20 h	β, γ	moderate (gr. III)	liquid + gaseous
134	Caesium-134	^{134}Cs	2.1 y	β, γ hard	moderate (gr. III)	liquid + gaseous
135	Caesium-135	^{135}Cs	2.3×10^{6} y	β	moderate (gr. III)	liquid + gaseous
137	Caesium-137	^{137}Cs	30 y	β, γ hard	moderate (gr. III)	liquid + gaseous
144	Cerium-144	^{144}Ce	285 d	β, γ	high (gr. II)	liquid + gaseous
154	Europium-154	^{154}Eu	8.6 y	β, γ	high (gr. II)	liquid
155	Europium-155	^{155}Eu	4.7 y	β, γ	high (gr. II)	liquid
230	Thorium-230	^{230}Th	75,000 y	α,γ	very high (gr. I)	liquid
232	Uranium-232	^{232}U	69 y	α, γ	very high (gr. I)	liquid
233	Uranium-233	^{233}U	162,000 y	α,γ	very high (gr. I)	liquid
234	Uranium-234	^{234}U	245,400 y	α	very high (gr. I)	liquid + gaseous
235	Uranium-235	^{235}U	7.1×10^{8} y	α, γ	very high (gr. I)	liquid + gaseous
236	Uranium-236	^{236}U	2.3×10^{7} y	α	high (gr. II)	liquid
237	Neptunium-237	^{237}Np	2.1×10^{6} y	α,γ	very high (gr. I)	liquid
238	Uranium-238	^{238}U	4.47×10^{9} y	α,γ	low (gr. IV)	liquid + gaseous
238	Plutonium-238	^{238}Pu	86.4 y	α	very high (gr. I)	liquid + gaseous
239	Plutonium-239	^{239}Pu	24,390 y	α, γ	very high (gr. I)	liquid + gaseous
240	Plutonium-240	^{240}Pu	6,563 y	α	very high (gr. I)	liquid + gaseous
241	Americium-241	^{241}Am	432.2 y	α, γ	very high (gr. I)	liquid + gaseous
241	Plutonium-241	^{241}Pu	14.4 y	β	very high (gr. I)	liquid
242	Curium-242	^{242}Cm	163 d	α	very high (gr. I)	liquid
244	Curium-244	^{244}Cm	18 y	α, γ	very high (gr. I)	liquid

(1) This table provides details about all radionuclides for which measures in environmental releases and/or in the environment are used in the report, plus other related radionuclides. They are ranked by number of mass.

(2) Radioactivity: α = alpha, β = beta, γ = gamma

(3) The classification in groups of radiotoxicity (gr. I to IV) is provided by the French regulation, Decree n° 86-1103.

GLOSSARY

ACC	Atelier de Compactage des Coques
ACRO	Association pour le Contrôle de la Radioactivité dans l'Ouest
AECL	Atomic Energy of Canada Limited
AGR	Advanced Gas-cooled Reactors
ALARA	As Low As Reasonably Achievable
ANDRA	Agence Nationale pour la Gestion des Déchets Radioactifs
ASN	Autorité de sûreté nucléaire
AT1	Atelier Pilote de Retraitement, UP2-400
BAT	Best Available Technique, or Best Available Technology
BEP	Best Environmental Practice
BNFL	British Nuclear Fuel Limited
BRH	Bundesrechnungshof
BSN	Bulletin de Sûreté Nucléaire
BST1	Plutonium oxide storage facility, UP2-400
BWR	Boiling Water Reactor
CANDU	Canada Deuterium Uranium reactor
CASTOR	Nuclear transport container type
CCPAH	Comité contre la Pollution Atomique dans La Hague
CRILAN	Comité Régional d'Information et de Luttes Anti-Nucléaires
CEA	Commissariat à l'Énergie Atomique
CEAA	Canadian Environmental Assessment Agency
CEC	Commission of the European Communities
CEDA	Consultative Exercise on Dose Assessments
CEGB	Central Electricity Generating Board
CEPN	Centre d'Étude sur l'évaluation de la Protection dans le domaine Nucléaire
CFDD	Commission Française du Développement Durable
CFDT	Confédération Française du Travail
CFIL	Council Food Intervention Level
CILH	Commission d'Information de La Hague
CNE	Commission Nationale d'Évaluation
CNIC	Citizens Nuclear Information Centre
CNPE	Centre Nucléaire de Production d'Électricité
COGEMA	Compagnie Générale des Matières Nucléaires
COMARE	Committee on the Medical Aspects of Radiation in the Environment
CORE	Cumbrians Opposed to a Radioactive Environment
COSYMA	COde SYstem from MAria
CRII-Rad	Commission de Recherche et d'Information Indépendantes sur la Radioactivité
CSA	Centre de Stockage de l'Aube
CSERGE	Centre for Social and Economic Research on the Global Environment
CSM	Centre de Stockage de la Manche
CSPI	Commission Spéciale et Permanente d'Information
DEFRA	Department of Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions
DG	Directorate General
DNA	Desoxyribonucleic Acid
DOE	Department of Energy
DRIRE	Direction Régionale de l'Industrie, de la Recherche et de l'Environnement
DSIN	Direction de la Sûreté des Installations Nucléaires
DWG	Discharges Working Group, BNFL Stakeholder Dialogue
EARP	Enhanced Actinide Removal Plant
EBR	Experimental Breeder Reactor

EDF	Électricité de France
EDS	Entreposage de Déchets Solides
EC	European Commission
EC	European Community
EEC	European Economic Community
EP	European Parliament
EPA	Environmental Protection Agency
EU	European Union
EURATOM	European Atomic Energy Treaty
EWI	Energie Wirtschaftliches Institut
FBR	Fast Breeder Reactor
FOE	Friends of the Earth
FSA	Food Standard Agency
GE	General Electric
GEA	Groupe d'Études Atomiques de la Marine Nationale
GRNC	Groupe Radio-écologique Nord-Cotentin
GRS	Gesellschaft für Anlagen und Reaktorsicherheit
GSIEN	Groupement de Scientifiques pour l'Information sur l'Énergie Nucléaire
HAL	Highly Active Liquid
HAO	Haute Activité Oxyde, UP2-400
HSE	Health and Safety Executive
HLW	High-Level Waste
HMIP	Her Majesty's Inspectorate of Probation
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate Level Waste
IEER	Institute for Energy and Environmental Research
INB	Installation Nucléaire de Base
INES	International Nuclear Event Scale
INSERM	Institut National de la Santé et de la Recherche Médicale
IPSN	Institut de Protection et de Sûreté Nucléaire
IRSS	Institute for Resource and Security Studies
KfK	Kernforschungszentrum, Karlsruhe
LET	Linear Energy Transfer
LLD	Lower Limit of Detection
LLW	Low Level Waste
LNT	Linear No-Threshold
LWR	Light Water Reactor
MAC	Medium Activity Concentrate
MAFF	Ministry of Agriculture, Fisheries and Food
MARINA	EC Programme on Radiological Exposure from Radioactivity in North European Waters
MEP	Member of European Parliament
MOX	Mixed Oxide fuel
MTR	Material Testing Reactor
NAC	Nuclear Assurance Corporation
NAGRA	Nationalen Genossenschaft für die Lagerung radioaktiven Abfälle
NCRP	National Council on Radiation Protection
NEA	Nuclear Energy Agency (OECD)
NII	Nuclear Installations Inspectorate
NPH	Storage facility, La Hague plant
NRC	Nuclear Regulatory Commission
NRPA	Norwegian Radiation Protection Authority
NRPB	National Radiological Protection Board
NUHOM	Storage cask system
OBT	Organically Bound Tritium
OECD	Organisation for Economic Co-operation and Development

OPECST	Office Parlementaire d'Évaluation des Choix Scientifiques et Technologiques
OPRI	Office de Protection contre les Rayonnements Ionisants
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
PAE-KfK	Projekt Andere Entsorgung at the Kernforschungszentrum Karlsruhe
PARCOM	Paris Commission
PFR	Prototype Fast Reactor
PHWR	Pressurized Heavy Water Reactors
POST	Parliamentary Office of Science and Technology
PPI	Paternal Preconception Irradiation
PRA	Probabilistic Risk Assessment
PSC	Public Service Commission
PWR	Pressurized Water Reactor
R&D	Research and Development
R1	Shearing plant, UP2-800
R7	Vitrification plant, UP2-800
RAT	Réseau des Amis de la Terre
REPU	Reprocessed Uranium
RIFE	Radioactivity In Food and the Environment
RNR	Réacteur à Neutrons Rapides
RWE	Rhine-Westfalische Energie
RWMAC	Radioactive Waste Management Advisory Committee
SEA	Single European Act
SIR	Standardized Incidence Ratio
SIXEP	Site Ionisation and Exchange Plant
STA	Science and Technology Agency
STE	Station de Traitement des Effluents
STOA	Scientific and Technological Option Assessment
T1	Shearing plant, UP3
T2	Separation plant, UP3
T7	Vitrification plant, UP3
THORP	Thermal Oxide Reprocessing Plant
UK	United Kingdom
UN	United Nations
UNGG	Uranium Naturel Graphite Gaz reactor
UNSCEAR	United Nations Committee on the Effects of Atomic Radiation
UOX	Uranium Oxide fuel
UP2-400	Usine de Plutonium 2-400
UP2-800	Usine de Plutonium 2-800
UP3	Usine de Plutonium 3
US	United States
USSR	Union of Soviet Socialist Republics
VDEW	Vereinigung Deutscher Elektrizitätswerke
VSC	Ventilated Storage Cask system
VVER	Vodiano Vodianoi Energuietitcheski Reaktor
WISE-Paris	World Information Service on Energy-Paris
WWG	Waste Working Group, BNFL Stakeholder Dialogue

Table 47 Main Units Used

a	annum	**Gy**	Gray	**t**	ton
Bq	Becquerel	**h**	hour	**tHM**	ton of heavy metal
°C	Celsius	**l**	litre	**We**	electric Watt
Ci	Curie	**m**	meter	**Wd**	Watt.day
eV	electron.Volt	**s**	second	**Wh**	Watt.hour
g	gramme	**Sv**	Sievert	**y**	year

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EVALUATION REPORT PROF. CROUDACE

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Assessors' credentials and interests

The Geosciences Advisory Unit is a university-based consultancy that carries out commissioned research contracts for a variety of clients in the UK including the nuclear industry, government agencies and local government groups. It is chosen by these clients on the basis of its perceived independence and its proven capability in the field of radiochemistry and environmental radioactivity. The Unit also sponsors PhD studentships, often through partial industry support, in the field of environmental radioactivity. Two significant contracts are held with two large civil authority groups one in Northern Ireland (NIRMCC) and the other in southern England (SERMG). These two consortia have existed since the late 1980s and are concerned with radioactive contamination arising from nuclear sites but particularly from Sellafield (for NIRMCC) and La Hague (for SERMG). The Geosciences Advisory Unit was invited to contribute to the STOA assessment through advocacy from Roy Perry MEP.

1. Introduction

The STOA report (Aug 2001) represents an assessment that was carried out by WISE-Paris under the direction of Mycle Schneider. It arose out of a petition from Hamburg citizens headed by Dr W Nachtwey in 1995 (393/95). The main message of the petition was a request to the European Parliament 'to prevent any further nuclear pollution of the oceans'. The 153 page report had nine contributors two of whom are cited as 'independent consultants'.

2. General Comments

The STOA Report has drawn on a significant amount of material taken from a wide variety of sources. These include official publications from international agencies, government and non-government organisations, literature published in international scientific journals, conference proceeding etc. The report presents an historical perspective for each site, relevant discharge and environmental impact data, accident records, radioactive dose implications, putative health effects and accident scenarios. Data for each reprocessing facility are presented as two separate case studies. Aspects of radioactive discharges to the atmosphere and to the marine environment are covered along with indications of environmental monitoring and the consequent accumulation of radionuclides in marine biota and sediment. The potential for future accidents/disasters involving stored high level waste at each site are also presented. Although, rather speculative and arguably alarmist the point is well taken especially with recent terrorist events. The controversial area of claimed health effects, in particular a statistically significant excess of childhood cancer, are presented but it is conceded no proven radiation link exists and no explanation can be found.

The original historical needs for reprocessing plants has passed but clearly the complex interplay of national political and financial interests has acted as an obstacle to change. However, external political pressures, the changing worldview and changing market requirements mean that the writing is on the wall for these plants. The STOA report only briefly mentions some planned changes that will occur in the UK. It is clear from some recent UK documents ***(DETR UK Strategy for Radioactive Discharges 2001-2020)*** that OSPAR obligations will force a wind down of activities at Sellafield. This is inevitable unless some extraordinary technology is developed that can arrest discharges and disable waste safely.

Overall this is an interesting document that has assembled an array of data from various sources in an attempt to build a persuasive case for ceasing reprocessing operations in France and the UK. We suspect however, that these countries (perhaps reluctantly) have already accepted the case and that a planned winding down is underway. The STOA document provides a number of good reasons for curtailing nuclear reprocessing in favour of fuel storage on safety and financial grounds. The rate at which all of these seemingly inevitable changes will occur is the key question. . There are several areas of the report that require re-appraisal and the details of these are given under **'Specific criticisms and suggestions'** .

3. Specific criticisms and suggestions:

There are a number of issues that we would question in the report. Consideration of some or all of these could lead to improvements in the report if it were redrafted.

1. The report would have benefited from a clear statement on the background of the WISE-Paris organisation and short biographies of the contributors. This information would have made clear any potential biases or vested interests. Even a scan of the WISE-Paris WEB-site does not make clear their generalised source of funding or affiliation(s). My suspicion is that they are a pressure group and without a transparent profile readers will have uncertainty judging the objectivity of the report. I would also be interested to learn how the EP awarded this contract to WISE-Paris – was it by invitation or through a competitive tender process ?

2. The two reprocessing plants are a legacy of the Cold War and originated before any European agreements had come into force. It is true that both organisations (or governments) have invested (significant) funds in reprocessing of spent fuel for developing civil nuclear programmes (mixed oxide fuel). The STOA report criticises both organisations for not having complied with the strictures of the EURATOM Treaty. It is not clear whether these can be applied retrospectively - or is it that only **new practices** require to be notified. Have there been any clear transgressions of the EURATOM treaty by the UK and France and if so what are the official explanations for such transgressions?

3. In the executive summary (page 5) it is noted that doses to critical groups in the 1970s and 1980s exceeded the current UK dose constraints. It is misleading to compare historical critical group doses with current dose constraints.

4. In terms of collective dose the current contribution from each of these two plants now appears to be moderate and is a small fraction of the average dose from natural (background) sources (~1%). A typical natural backround annual dose might be construed to be ~ 2 mSv. We are aware that two of the contributors (Fairlie & Sumner) disagree with this approach (Annexe 6d). Part of their argument relates to the wide range of background radioactivity; for example high backgrounds may pertain to radon affected areas. Our point is not to invoke *natural = good* and *man-made = bad* but to assume that living creatures are able to cope with radioactivity to a degree and that very small increases may not produce significant effects. The current dose to critical consumers (for Cumbria) adds perhaps as much as 20% to the 'normal' background dose. We do not mean to imply current discharges are insignificant or acceptable but expect the contractors to provide a balanced presentation of the facts. It is acknowledged that the dosimetric consequences of past discharges will have been appreciably greater than the current state.

5. **Natural Radioactive wastes:** There are several plants in the EU that process phosphate ores and these discharge radioactive wastes into the marine or estuarine environment. These discharges can involve (at least historically) appreciable activities (and hence doses) of natural emitters (uranium, thorium, radium, lead, polonium etc). For comparison purposes a section on these could also be included in this report since it will help put reprocessing wastes in context with other radioactive wastes. Politically, the phosphate industry has avoided (perhaps anomalously!) the scrutiny that has fallen on the nuclear industry. Another tangential point is that some of these phosphate plants now import raw phosphoric acid from the source countries rather than processing the raw ore. This serves to transfer the radioactive waste issue to these countries (often Third World). The EU might consider that it should take a share of this responsibility for the environmental impact caused by such operations. Again the writers of the STOA

report may be criticised for non-objectivity by ignoring other significant sources of radioactive discharges into the marine environment.

6. No mention is made of the new Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The UK is soon to ratify this Joint Convention - should further comment be made on this ?

7. The two **case studies** (*viz.* for Sellafield and La Hague) present much valuable information. The use of single tables to summarise and incorporate specific aspects of the two plants would have made information extraction easier. We would have liked the two plants to have been compared more frequently rather than the tendency to deal with each separately. Aspects of each site such as discharge authorisations, individual radionuclide discharges to air and sea, stored inventories of medium and high level waste etc could have been compared for the two sites. Where deficiencies in data existed, as is implied on page 43 for the La Hague plant, this would have served as a powerful message that the French should perhaps be as open as the UK.

8. The report does not make clear what the environmental impact differences for the two plants are although such information does exist in the literature. The marine environments around Sellafield and La Hague record the history of discharges in different ways. The bed of the Irish Sea, offshore from Sellafield, contains a sub-tidal mudbelt and suspended muddy sediment scavenges many radionuclides (to a greater or lesser extent depending on the radionuclide) from the effluent. This mudbelt acts as a store of historical discharges which is tapped during bottom current movements and storms. At La Hague a combination of local hydrodynamics (rapid marine currents) and the mineralogy of the sediments (less clay and more sand and carbonate) make efficient local scavenging less likely. Thus many La Hague-derived radionuclides are transported into the North Sea and further north. A portion of some particle-reactive radionuclides (e.g. Co, Pu, Am) may concentrate in the central Channel (Boust and Bailly du Bois & Geugueniat *Cont. Shelf Res. 1999).* This information is perhaps worth including in a section on environmental impact.

9. There is an implication (perhaps unintended) on Page 82 (Annexe 5) that scientists are culpable for carrying out research in environmental radioactivity - in some way they are criticised for using the environment as a laboratory. This is a ridiculous assertion if this implication was intentional. Many of the scientists who carrried out this work are independent of national policy decisions concerning reprocessing or otherwise. Some studies are officially funded (e.g. CEFAS studies on ^{99}Tc movement) and set out to determine radionuclide behaviour in the environment. These organisations have no responsibility for any discharge practices and they should not be admonished for their work. Indeed the results from these studies enable objective impact assessments to be made. Other studies are driven by scientific curiosity and are funded by scientific research councils and other sources (see the Wigley PhD study on ^{99}Tc mentioned in 12 below).

10. In section 4.2.4.4, the maximum beta energy for ^{3}H is quoted as 18 MeV. In fact the value is 18.6 keV. In the same section, it is noted that 'tritiated foodstuffs (OBT) have much longer half lives, which are poorly defined and may extend to several years'. The term OBT (organically-bound tritium) more correctly refers to tritium bound irreversibly in an organic molecule and not specifically to ^{3}H present in foodstuffs. The observed half-life will depend on the organic molecule that the ^{3}H is associated with.

    It is rather questionable that 'hardly anything' is known about ^{99}Tc speciation and transport through environmental pathways. A more detailed literature search of this area would prove useful (e.g. Desmet G. and Myttenaere C. (eds) Technetium in the environment, Elsevier, London, UK pp419).

11. 'In addition, important information about the behaviour of ^{99}Tc is not being obtained for tide washed pastures .....' Annexe 5 (page 82). This is not entirely the case since Wigley studied ^{99}Tc in Cumbrian

saltmarshes [Mechanisms of accumulation and migration of ^{99}Tc in saltmarsh sediments, 2000 PhD, University of Southampton (supervisors Croudace & Warwick).

12. In section 5.3.3 it is noted that ^{99}Tc is discharged into the environment mainly from Magnox fuel reprocessing. However, it is stated that the absence of ^{99}Tc in La Hague discharges is as a result of its low abundance in LWR fuel. As the thermal neutron fission yield of ^{99}Tc is *ca* 6% in both cases it is unlikely that this alone is the cause of the differences. According to Luykx (1986), La Hague discharged 11.7 TBq of ^{99}Tc during 1983 whilst Sellafield only discharged 4.4 TBq. Also in Figure 13, a comparison between Sellafield and La Hague discharges is provided showing a significant La Hague ^{99}Tc discharge. It is therefore worth considering in more detail the impact of La Hague ^{99}Tc discharges.
    Luykx F. (1986) Technetium discharges into the environment. In Desmet G. and Myttenaere C. (eds) Technetium in the environment, Elsevier, London, UK pp419

13. In section 8.1.1 it states that 'In the UK, there is no program for the use of MOX fuel.' We are not sure that this is the case as we thought that some reactors had been granted licenses to run with MOX loads.

14. The reference to Doll *et al* (1990) in section 5.6.2 is not included in the reference list.

Appendixes

The Geosciences Advisory Unit is a consultancy/research group based at the Southampton Oceanography Centre that specialises in environmental geochemistry and radioactivity. The purpose of the unit is to carry out contract work that has a direct benefit to the research activities of the University. The Unit also sponsors PhD studentships in environmental radioactivity as well as supporting research in radioanalytical chemistry. The Unit has analytical laboratories that are equipped to the best international standards.

The Southampton Oceanography Centre opened in 1994 and was formed through a partnership between the Natural Environment Research Council (NERC) and the University of Southampton.

Recent contracts held by the GAU

Contractor	Project description
Southern England Radiation Monitoring Group. SERMG: - a 47 local authority consortium	A regional environmental radioactivity survey: a 15 year programme.
Newbury District Council and B&D District Council	Greenham Common Survey: a study of an alleged military nuclear accident in west Berkshire.
Northern Ireland Radiation Monitoring Group	Regional environmental radioactivity survey
Orkney Islands Harbour Board	Actinides in marine biota
AWE Hunting-BRAE	U and Pu in the environments around the AWE sites
States of Jersey	Radionuclide discharges from La Hague
Greenpeace Research Laboratories	^{99}Tc in UK and European waters
Food Standards Agency	Organically-bound Tritium in the environment

Ian Croudace (BSc, PhD) is the founding director of the Geosciences Advisory Unit and has 25 years research experience and has written over 90 scientific publications and reports. He is also a Senior Lecturer (environmental geology and geochemistry) at the Southampton Oceanography Centre. He obtained his PhD in geochemistry from the University of Birmingham and subsequently undertook post-doctoral research at the University of Paris VI and at the Centre d'Etude Nucleaires, Saclay before arriving at Southampton in 1983 to carry out research and teaching in environmental radioactivity and environmental geochemistry. He is the project coordinator for the Southern England Radiation Monitoring Programme and the Northern Ireland Radioactivity Monitoring Coordinating Committee (NIRMCC).

Phillip Warwick (BSc, PhD, CChem, MRSC) is deputy Director of the Geosciences Advisory Unit. He previously managed the Environmental and Biological Chemistry laboratory for the Atomic Energy Authority at Winfrith. He is a specialist in radio-analytical chemistry, has 14 years research experience in environmental radiochemistry and obtained his PhD in environmental radioactivity at the University of Southampton. He has written over 20 scientific papers and numerous scientific reports.

Relevant research publications by GAU staff since 1996 (in chronological order)
GAU Staff and associates are in bold

Warwick P.E., Croudace I.W. and Carpenter R. **(1996)** Review of analytical techniques for the determination of americium-241 in soils and sediments. *Appl. Radiat. Isot.,* **47.** 627-642.

Croudace I.W., Warwick P.E., Taylor R.N. and Dee S.J. (1997) Greening the Common. *Chem. Brit*., 26-29.

Toole J., Adsley I., Hearn R., Wildner H., Montgomery N., **Croudace I., Warwick P. & Taylor R. (1997).** Status of analytical techniques for the measurement of uranium isotopic signatures. Workshop on the status of measurement techniques for the identification of nuclear signatures. 25-27 February 1997. Geel Belgium. Report EUR 17313.

Taylor R.N., Croudace I.W., Warwick P.E. and Dee S.J. (1998) Precise and rapid determination of $^{238}U/^{235}U$ and uranium concentrations in soil samples using thermal ionisation mass spectrometry. *Chem. Geol.* **144**, 73-80.

Croudace I.W., Warwick P.E., Taylor R.N. , Dee S.J., Milton J.A. **and Oh J.S (1998)** The determination of actinide elements in environmental materials using a borate fusion followed by ion-exchange/extraction chromatography. *Radioact. Radiochem.* **9**, 41-48.

Croudace I.W., Warwick P.E.,**Taylor R.N. and Dee S.J. (1998).** Rapid procedure for plutonium and uranium determination in soils using a borate fusion followed by ion-exchange and extraction chromatography - *Analyt. Chim. Acta*. **371**, 217-225.

Warwick P.E., Croudace I.W. & Howard A.G. **(1999)** An improved technique for the routine determination of tritiated water in aqueous samples – *Analyt. Chim. Acta.* **382**, 225-231.

Warwick P.E., Croudace I.W. and Dale A.A. **(1999)** An optimised and robust method for the determination of uranium and plutonium in aqueous samples**.** *Appl. Radiat. Isot.*. **50,** 579-583.

Cundy A.B., Croudace I.W., P.E.Warwick and Bains M.E. **(1999)** Environmental decline of radionuclides following nuclear reactor closure: a U.K. case study. *Env. Sci. Technol*.. **33**, 2841-2849.

Croudace I.W., Warwick P.E., Taylor R.N. and Cundy A.B. (2000) Investigation of an alleged nuclear incident at Greenham Common airbase using TI-mass spectrometric measurements of uranium isotopes. *Env. Sci. Technol*., **34**, 4496-4503.

Taylor R.N., Warneke T., Milton J.A., Croudace I.W., Warwick P.E. and Nesbitt R.W. (2001) Plutonium isotope ratio analysis at femtogram to nanogram levels by multicollector ICP-MS. *J. Anal. At. Spectrom.*. **16**, 279-284.

Warwick P.E., Cundy A.B., Croudace I.W., Bains M.E.D. and Dale A.A. **(2001)** The uptake of iron-55 by marine sediment, macro-algae and biota following discharge from a nuclear power station. *Env. Sci. Technol.,* **33**, 35.

Warwick P.E., Croudace I.W. and Oh J.S. (2001) Radiochemical determination of ^{241}Am and Pu(alpha) in environmental materials. *Anal Chem*. **73**, 3410 – 3416.

Evaluation Report Dr. Mitchell

P.I. Mitchell

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I have examined the above mentioned report in considerable detail and wish to make a number of comments, some of a broad and rather general nature and others of a more specific character. If I may start with some general impressions.

General comments:

The report contains a wealth of background information for legislators and regulators and, in the main, provides a lucid and uncomplicated description of the main issues attending the reprocessing of spent nuclear fuel at the present time. It provides background to the origins of reprocessing and to the implications of reprocessing in comparison with alternative (non-reprocessing) management options such as dry storage. It also provides a valuable summary of the legal framework at both international and European level that now governs all activities relating to nuclear reprocessing, including radioactive waste discharges to the environment. All of this I have found to be helpful and informative.

Overall, the report's treatment of annual discharge levels (gaseous and liquid) appears reasonable to this reviewer, though I would comment that more emphasis might have been given to the very substantial reductions achieved at Sellafield for many nuclides and, in particular, radiocaesium and the transuranics (mainly plutonium and americium), since the mid- to late-1970s. The report highlights more recent increases in the releases of several important, long-lived radionuclides, e.g. C-14, Tc-99 and I-129, though it does recognise that from the individual dose/critical group perspective their radiologically importance is very much less than that of the transuranics.

The report deals objectively with the subject of doses to individual members of critical groups and, in the context of Sellafield, states clearly that the average individual dose to the Sellafield critical group from current discharges is about 0.21 mSv compared to the UK dose constraint of 0.30 mSv. However, the presentation of equivalent data on critical group doses in the executive summary could be seem as somewhat disingenuous, as past doses are compared with current UK and EU limits, instead of with the limits in place at the time in question.

The report also addresses certain issues in radiobiology concerning health effects from exposure to ionising radiation and places much stress on the importance of the concept of collective dose when evaluating the impact of reprocessing in comparison to alternative strategies. I am not impressed by this section of the report as I consider it to be incomplete in more than one regard and, moreover, believe that it places undue emphasis on collective dose. I shall return to this last point below.

Amongst other matters, the report discusses the apparent higher incidence of leukaemia in the regions surrounding the Sellafield and La Hague reprocessing plants. This is an issue of great sensitivity, particularly in so far as the public are concerned, and one which has already received enormous publicity in both countries as well in the European Union. While the authors concede that a causal relationship with environmental radioactivity has not, in fact, been established (and for all we know may never be established), the tenor and emphasis of their conclusions in this area does not impress the reviewer. I have a genuine concern about objectivity here. In effect, I sense that the report may have departed from strict objectivity in some at least of the conclusions inferred.

Specific comments:

Regarding expected future discharges from Sellafield (Sect. 5.3.4.), the report makes reference to internal BNFL documents (undated) which were leaked to the UK press and various environmental groups in June 2001, and which envisage increases in radionuclide releases in the future such that currently authorised discharge limits are likely to be approached or exceeded in the case of a number of radionuclides. Surely this is, in the first place, a matter for the authorising authority in the UK, who are highly unlikely to agree to increases in these limits in the light of the OSPAR Convention.

The report makes reference to the accumulation of transuranium radionuclides in sediment deposits throughout coastal environments following their release from the above-mentioned reprocessing plants. Whilst this is, of course, true scientifically, it is important to appreciate that actual concentrations of these radionuclides in, for example, the seabed sediments of the north-eastern Irish Sea are now declining as a consequence of reductions in discharges since the mid-1970s, as well as remobilisation/desorption from previously contaminated sediment, followed by transfer and dispersal by tides and currents. Farther afield (e.g. the east coast of Ireland) the reduction is less evident but is, nevertheless, now beginning to take place.

It is my understanding that important new evidence has recently come to light in regard to exposure to alpha particle radiation which would suggest that there may be an dose/exposure threshold below which there are no injurious effects. If this proves to be the case and, I stress that we speak only of alpha irradiation, it will profoundly alter the weight previously given to the concept of collective dose.

Regarding the report's conclusions on health effects around La Hague, I would make the following observations:

The Nord-Cotentin Radiological Group's (GRNC) final conclusions were that epidemiological studies have shown that the total number of cases of leukaemia expected in the Beaumont-Hague canton in the period 1978-96 would be of the order of two if the occurrence rate of this disease was the same as the value observed nationally. In fact, four cases were observed. Nevertheless, this difference was not considered to be statistically significant. Further, the reconstruction of exposures from nuclear installations, as was performed by the Nord-Cotentin Radiological Group, lead to a calculated number of 0.0014 cases of radiation-induced leukaemia during the same period. However, they stressed that this result was an average estimate and that the margins of uncertainty involved could not be quantified at that stage. Indeed, most of the members of the GRNC considered the results obtained to be a 'best estimate', which needs to be further investigated, espcialaly regarding analysis of the uncertainties involved.

The La Hague results may be compared with the results of similar studies carried out in the UK around the Sellafield and Dounray reprocessing plants. The conclusion of the British studies was that the observed number of cases of leukaemia cannot be explained by discharges from nuclear installations.

I question the report's conclusion that a serious accident involving loss of coolant to one or more of 21 high level liquid radioactive waste (above ground) storage tanks at Sellafield might result, in the long-term, globally, to over one million fatal cancer cases. Nevertheless, and in the light of recent events, it is patently evident that this whole area of nuclear security needs to be revisited and thoroughly re-examined from every possible perspective.

The report expresses strong doubts that the European Commission is in a position to ensure the full and efficient implemenation of *Articles 35* and *37* of the Euratom Treaty. Although I am not in a position to

comment, one way or the other, on the implementation of *Article 35*, I have served for over 15 years as a member of an expert group that advises the Commission with in the framework of *Article 37* and consider that my experiences here permit me to comment with some authority. Unlie the authors of the report, I believe that the Commission has found itself in a position to fulfill its obligations under *Article 37* and that, in general, it has done so efficiently and expeditiously. In my recall, Member States have usually been cooperative and have provided the necessary information and data to enable the Commission (and its advisers) formulate and publish an informed and sound opinion. The report's comments regarding the paucity of man-months over a four and a half month period) devoted to the La Hague opinion is rather meaningless, as it takes no account whatsoever of the time taken by the 40-odd group of experts, who also studied the documentation and data in advance of meeting in plenary session with the Commission, national representatives, and technical representatives of the operator.

Finally, regarding the management of plutonium stocks, I agree strongly with the report's finding that the European Parliament and the European Commission must ensure that the Euratom Safeguards Agency has the necessary funding to carry out its mission of verification rigorously and efficiently. I do not, however, agree with the suggestion that the Parliament introduce legislation to prohibit the separation of plutonium unless a utility can demonstrate a short term use for the separated plutonium.

In conclusion, I hope the above observations prove helpful to members of the STOA Panel in their deliberations and would be more than please to amplify the above or answer any questions, if required.

Yours sincerely,

Prof. Peter. I. Mitchell PhD CPhys FInstP

(Head, Department of Experimental Physics, UCD)

Evaluation Report Prof. J.-C. Zerbib

Jean Claude Zerbib October 2001

CRITICAL ANALYSIS OF THE WISE-PARIS REPORT

The WISE-Paris report is a major report which deserves much more detailed analysis than we are able to carry out in a short space of time. We will be looking at:

- inspections of nuclear installations,
- releases of liquid and gaseous radioactive effluents,
- contamination of the environment,
- dosimetric impact,

but focusing in particular on releases of effluents. Monitoring of environmental contamination and calculation of the associated dosimetric impacts require substantial work (validation of measurement data, the computation methods used, hypotheses made in relation to consumption, etc.).

We will not be able to address important points such as alternatives to reprocessing in the management of waste, stockpiles of reprocessed plutonium and uranium or irradiated fuels. Such problems exist, however, whatever technical and political options the Member States choose in the medium to long term, for it is necessary at very least to manage the material produced to date.

1 - Inspection of nuclear installations and the 'Euratom Treaty'

Fuel reprocessing plants are composed of a series of installations which operate 'in series', each with a distinct function, from reception of casks containing fuel assemblies to the storage and consignment of conditioned waste and radioactive raw materials (uranium, plutonium). Each of these installations has a specific single function but is nevertheless sufficiently complex to be considered a 'basic nuclear facility' (INB) under French regulations. INBs are covered by 'safety records', which are compiled at each of stage in their life, from planning to entry into service, and are subject to regulatory authority approval.

Irrespective of how appropriate and effective the intrinsic safety arrangements and any measures implemented at a site like Sellafield or La Hague are deemed to be, the experts responsible for inspections require a great deal of time to obtain all of the data, given that we expect them to produce a totally independent critical analysis. However, such analyses cannot be produced without the need to consult the operators and safety authorities, who have also conducted critical analyses and inspected the facilities on the site.

In view of the foregoing, if the information supplied in the WISE-Paris report (2 man-months over a 4.5 month period) concerning the time Euratom inspectors spend inspecting installations is accurate, we can also conclude that the Commission's means for applying the provisions of the Euratom Treaty are not commensurate with the requirements of Article 37 thereof.

2 - Discharges of radioactive liquid and gaseous effluents from reprocessing plants

Analysis of the report, which compares releases of radioactive waste from irradiated fuel reprocessing sites at Sellafield and La Hague, as well as the associated dosimetric impacts, necessitates prior verification of the validity of the data on which the WISE-Paris findings are based. For that purpose, we have mainly used documents published by the EC pursuant to the Euratom Treaty [1-3], the NRPB[68] [5], BNFL[69] [6-8], the UK authorities responsible for monitoring the environment and consumer products [9-13], and the GRNC[70] [14]:

- Table 1 presents, for the UK and French plants, from their entry into service to 1992, and then for the period 1993-1999, figures for the cumulative activity of long-lived radionuclides present in *liquid effluents*, based on data from publications 1-14.
- Table 2 presents, for the same periods, figures for the cumulative activity of long-lived radionuclides present in *gaseous effluents* from La Hague and Sellafield [1-14].

We have chosen these periods in view of the report's findings concerning the overall track record for discharges from Sellafield and the fact that 1992 marked a turning point for both sites[71].

Generally speaking, two trends can be observed at the UK and French plants:

- a clear trend towards a *decrease* in the activity of discharged material, mainly concerning radionuclides with a half-life of less than about thirty years (incl. caesium-137 and strontium-90),
- an *increase* in the activity of effluents concerning radionuclides which pose problems owing to the complex processes needed to trap them (tritium and krypton-85) and/or the safety risks of long-term storage owing to their very long half-lives (technetium-99 and iodine-129).

The *decrease* is due to improved purification processes for liquid effluents (effluent separation, recycling, evaporation) and gaseous effluents (off-gas segregation, scrubber plants, use of special dust catchers prior to high-performance filtration).

The *increase* is directly linked to the increase in the volume of material reprocessed and in burnup. There is one exception, concerning the THORP plant (operational since 1994), which was equipped with a carbon-14 trapping system for gaseous effluents. However, the other facilities on the site are not equipped with such a system. THORP's share of ^{14}C releases from Sellafield was only 3.9% during the 1994-99 period.

We will be presenting, in Table 3, the key figures from the WISE report, in the light of which we will clarify what we have found by analysing the activity values in Tables 1 and 2.

[68] NRPB = National Radiological Protection Board

[69] BNFL = British Nuclear Fuels plc

[70] North Cotentin Radio-Ecological Group (GRNC), which has been commissioned by the Minister for the Environment and the State Secretary for Health to estimate levels of exposure to ionising radiation (from nuclear installations in the region) of population groups in the northern part of the Cotentin peninsula, the associated risk of leukaemia, and levels of uncertainty affecting such estimates.

[71] As from 1990-91, there was, at La Hague, a sizeable reduction in discharges whilst the tonnages reprocessed began to increase substantially (in 1994, the tonnage reprocessed was double what it had been in 1990-91). In the case of Sellafield, 1993 and 1994 were the years when the greatest tonnage of Magnox fuel was reprocessed (1664 t) and when THORP became operational.

➢ *Effluents from Sellafield:*

Apart from the increase in iodine-129 in gaseous discharges, which we are unable to confirm[72], as all the reports published provide different results, the WISE-Paris report data on releases of liquid and gaseous effluents have been verified in all cases.

- The report (p. 32) also indicates that plutonium has been deposited in the soil, the activity of which was put at 160-280 GBq in 1992. The record for *gaseous* effluents shown in Table 2 indicates aggregate releases to be far higher than that (3.7 TBq $^{239+240}$Pu and 23,7 TBq ^{241}Pu). As the site is on the coast, it is also necessary to have information on several other factors (prevailing winds and average wind speeds, chimney heights, etc.) in order to estimate the proportions of plutonium deposited in the soil and in the sea respectively.
- As regards plutonium in *liquid* effluents deposited in sea-bed sediment, the report (p. 33) cites an estimate from 1991 which puts the figure at **250-500** kg. Whilst it is possible to calculate the mass of plutonium-238 (0.19 kg) and plutonium-239 (5.1 kg) from the figures for discharges of isotopes 239 and 240 between 1951 and 1992, we have to make hypotheses for their relative proportions of the total activity of discharged material[73]. These depend on the figures for burnup of reprocessed fuels. An approximate approach would be to consider the activity of the various isotopes present in the effluents throughout the 1951-1992 period. The reported activity of isotopes ^{241}Pu / ^{239}Pu+^{240}Pu would indicate the average burnup of reprocessed fuel to be low (2000-4000 $MW_{th}j$). In this case, the weight of isotopes 239 and 240 would be between 171 and 209 kg and total plutonium between **176 and 214** kg. More precise calculations could be made if we had details of the tonnages, and burnup, of fuel reprocessed annually at Sellafield.

It is worth pointing out here the significance of the WISE-Paris approach, which looks at the overall figures for discharges in terms not only of the *activity* but also of the *mass* of the material released.

➢ *Effluents from La Hague:*

WISE-Paris indicates (p. 52) that measurements have not been taken for three radionuclides in *gaseous discharges* from La Hague, namely: *chlorine-36, strontium-90 and technetium-99.* In this connection, we can state that, at the request of the GRNC, special measurement exercises were conducted to verify whether measurable quantities were present in gaseous effluents from La Hague. Those exercises concerned releases of *chlorine-36* (produced as a result of activation of chlorine impurities possibly present in fuel) and *strontium-90* (a fission product):

- In the case of *chlorine-36*, inspections focused on a variety of indicators (meat, poultry, eggs, milk, cereals, soils and stream water). Measurements were also made using urine from people who, on the basis of meteorological data, are considered to live close to the point of maximum fallout. In the absence of meaningful measurement results, an evaluation of the activity of gaseous discharges considered for dose calculation purposes was made on the basis of a detection limit for ^{36}Cl in urine.
- In the case of *strontium-90*, two measurement exercises were conducted, which made it possible to calculate the maximum release on the basis of a detection limit (0.1 GBq per annum for 1999 and 2000).

[72] It is possible that a publication provided data which did not agree with those obtained by the NRPB [5] and used by COMARE [15]. We have on several occasions encountered data which indicates widely varying levels of activity for the same set of years.

[73] Plutonium-239 and plutonium-240 emit alpha particles of very similar energy levels (respectively 5.156 MeV and 5.168 MeV at the most intense), as a result of which it is generally *total* alpha energy that is measured rather than the energy for each isotope. However, the specific activity of the two isotopes differs: the mass of 1 TBq of plutonium-239 is 441 g, whereas that of 1 TBq of plutonium-240 is 119 g. Calculation of the mass of the two isotopes therefore requires some form of hypothesis to be made as regards distribution.

- It is true, however, that the absence of technetium (established by the measurements) in gaseous effluents has not been the subject of investigations such as were carried out in the case of chlorine-36 and strontium-90.
- The WISE-Paris report also cites a challenge raised by Mr Guillemette (p. 59), who disputed certain measurements for *strontium-90* that were taken at sea following the discovery by COGEMA in January 1980 of a crack in the sea discharge pipe. This challenge was taken into account by the GRNC, and a working party (to which Mr Guillemette belonged) studied the points raised. A report on the outcome of this review was published [16].
- WISE-Paris raised the problem posed by the discrepancies in the overall figures (24.6% on average between 1988 and 1993) observed in the case of *iodine-129* in liquid effluents. The GRNC had in fact noted this discrepancy ([14] fig. 25a and 25b) but had not offered any explanations as to its cause. It would appear to be linked to uncertainties attached to the measurement of ^{129}I, but a GRNC working party is to convene to study the problem. Experts from WISE-Paris will of course be part of that working party, which the GRNC plenary decided to set up.
- The report also considers alarming the difference noted between regulatory authorisations for liquid and gaseous effluent discharges from a plant such as La Hague and those from a nuclear reactor like Flamanville, 17km from the COGEMA site. There are objective differences between the hundred or so tonnes of fuel that make up the core of the reactor, whose maximum integrity is ensured, and a plant which cuts up and annually places in solution the equivalent of 16 reactor cores as powerful as those at Flamanville.
- As regards long-term effects, the problem concerns in particular radionuclides such as carbon-14, krypton-85, technetium-99 and iodine-129. This implicitly raises the following question: '*Should we ensure the best possible diffusion of such radionuclides or demand that they be trapped, despite the uncertainties as regards the durability of containment bearing in mind their very long half-lives (*^{14}C *- 5730 years,* ^{129}I *- 15.7 million years, and* ^{99}Tc *- 214 000 years)*?'

Obviously, responsibility for taking this decision must not rest with the nuclear power operator, but with the regulatory authorities.

➢ *Potential incidents at reprocessing plants*

The WISE-Paris report raises the issue of major fire risks in a radioactive material storage area (p. 53). After the attacks of 11 September 2001, the authorities responsible for safety will obviously have to rethink their reference scenarios and reassess malicious acts against INBs. In a reprocessing plant, the zones which potentially pose a high risk are those used for storing:

- fuel, in ponds or in dry areas (Sellafield and La Hague),
- fission products (Sellafield, for La Hague vitrifies these practically on line),
- plutonium oxide (Sellafield and La Hague).

3 - Environmental measures and assessment of radiation doses received by members of the public

The EC has evaluated the doses received by members of the public, exclusively on the basis of models, in the case of the plants at Sellafield and La Hague, in 1983 [1] and 1995 [2]. After calculating the levels of contamination (in the air, soil and sea) caused by discharges of liquid and gaseous effluents, the resulting doses (external exposure and inhalation) were estimated for people living 0.5 km from the point source (gaseous discharges) and up to 5 km away.

In the case of discharges into the sea, the level of exposure of a 'critical group' (fishermen) was evaluated, as well as the internal exposure of two groups who do, or do not, consume radioactively contaminated local produce. The doses were calculated by applying the coefficients published in CIPR30. A model was also used to evaluate the collective dose to the people of the European Community.

The WISE-Paris report cites from the work of the GRNC [15, 17], which:

- compiled as full an inventory as possible of the radionuclides present in liquid and gaseous discharges from La Hague from 1966 to 1996; radionuclides present in effluents, but not measured, were reconstituted;
- drew up an overview of all samples taken and types of measurement taken since La Hague became operational (1966);
- compared model-based forecasts with the results of measurements;
- made calculations of ingested activity and exposure levels based on people's habits and lifestyles, as indicated by locally conducted surveys;
- calculated doses to bone marrow for a cohort of individuals, doses to the whole body (effective dose) in the case of 'reference groups', and doses received in certain specific scenarios.

The WISE-Paris report stresses (p. 54) that this work is essentially based on field measurements taken by the operator (51%), the national marine (16%) and the national body responsible for radiological inspections at nuclear installations (OPRI) (17.5%). Whilst this is true, it should also be noted that this is the first time that a working party with a ministerial mandate has taken account (albeit to a very limited extent: 0.23%) of measurements taken by non-profit movements[74]- ACRO, CRII-RAD, GSIEN - and allowed their experts to participate in its work as a whole. The report therefore rightly draws attention to the small number of measurements taken by these bodies, which is evidence above all of the fact that independent expertise is not sought often enough and does not, in France, benefit from the necessary public- and private-sector aid.

WISE-Paris also stresses that the GRNC has not calculated the collective dose to the global population (p. 57). The report itself makes a calculation for the population of Europe (p. 63) using the model employed by the EC in 1995 [2].

The GRNC did not, in fact, make such calculations as they were not part of the remit conferred upon it by the French Ministry of the Environment and State Secretary for Health.

4 – Conclusions

The WISE-Paris report constitutes an important study of all the problems posed by fuel reprocessing at Sellafield and La Hague. Its structure, which we have not been able to subject to critical analysis in its entirety, does cover the problems which such industrial operations pose.

As regards the analysis of liquid and gaseous effluents from UK and French plants, a section we have studied in great detail, it is evident that the authors have been able to *assemble* and *use* substantial technical and scientific documentation.

Whilst some of the points addressed in this report are also covered in technical literature, we must point out that the report *has no equivalent* as far as overall consideration and critical analysis of each of the *'end of cycle'* problems posed by nuclear fuel are concerned. The many technical annexes are a useful supplement to the report, which, for all these reasons, deserves to be published so as to reach a wide readership.

[74] ACRO = Association for the monitoring of radioactivity in western France.
CRII-RAD = Commission for independent research and information concerning radioactivity.
GSIEN = Group of scientists for information on nuclear energy.

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