WISE-Paris
Service Mondial d'Information sur l'Energie
World Information Service on Energy
http://www.wise-paris.org • e-mail : secretariat@wise-paris.org
31-33 rue de la Colonie F-75013 PARIS • Tél. +33 1 45 65 47 93 • Fax +33 1 45 80 48 58

Joint Assessment

PLUTONIUM TRANSPORTS IN FRANCE
Safety and Security Concerns over the FS47 Transportation Cask

Yves Marignac, Xavier Coeytaux,[1]
John H. Large[2]
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BACKGROUND

Consignments of reactor-grade plutonium dioxide (PuO_2) separated at the COGEMA fuel reprocessing works at la Hague have and continue to be regularly transported overland to the MOX fuel fabrication plants at Cadarache and Marcoule in southern France. This involves a journey of about 800 km on the public road network with the plutonium being carried in sealed transportation casks designated FS47. Typically, nine to ten FS47 transportation casks are carried in each of two vehicles, with each individual cask holding approximately 15 kg PuO_2 (in total 280 to 300 kg per two vehicle convoy). On average and throughout the year, about 45 such journeys are undertaken every 8 or so days with the total amount of plutonium transported being around 12 tonnes per annum.

France is a signatory of the International Atomic Energy Agency *Convention on the Physical Protection of Nuclear Material* (IAEA274)[3] for which it claims to comply with the recommendations of INFCIRC/225/Rev.4 (IAEA225)[4] for the protection and security specified for *Category I* materials (i.e. highly fissile plutonium). In addition, France adopts the requirements of IAEA regulations TS-R-1 *Regulations for the Safe Transport of Radioactive Material*[5] under which transportation of radioactive materials has to be carried out in an approved manner, in this case by Type B(U) certified casks for which it claims the FS47 cask design is compliant.

However, since the beginning of 2003, on-the-ground observation[6] and reports of independent technical analysts[7] have challenged the safety and security of PuO_2 consignments when under road transportation from la Hague to southern France. In response to this increasing challenge and criticism, the French nuclear technical support organisation, the *Institut de radioprotection et de sûreté nucléaire* (IRSN), issued a rebuttal statement to consolidate its position.[8]

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1 Yves Marignac, Director, Xavier Coeytaux, Research Associate, WISE-Paris, Paris, France.

2 John H Large, Consulting Nuclear Engineer, Large & Associates, Consulting Engineers, London, UK.

3 IAEA, *Convention on the Physical Protection of Nuclear Material*, INFCIRC/274/Rev.1, May 1980.

4 IAEA, *The Physical Protection of Nuclear Material*, INFCIRC/225/Rev.4 (corrected), June 1999.

5 IAEA, TS-R-1 *Regulations for the Safe Transport of Radioactive Material*, Safety Standards Series No. ST-l Requirements, Edition, Vienna 1996.

6 Greenpeace France regularly reports the plutonium convoys on a dedicated web site http://www.stop-plutonium.org

7 Notably, WISE-Paris, France and Large & Associates, UK (see below).

8 IRSN, *Risques de rejet radioactif lors du transport routier de poudre d'oxyde de plutonium en colis FS47*, not dated (March/April 2004). http://www.irsn.fr/vf/05_inf/05_inf_1dossiers/05_inf_35_pu/05_inf_35_pu.shtm.

This briefing note reviews the IRSN rebuttal in terms of recent technical evaluations, technical evidence submitted in the United States, and technical papers relating the performance of the FS47 cask design when subject to credible accident and potential terrorist attack conditions.

AWAITED US PuO_2 SHIPMENT

In addition to the regular domestic French transports, the safety and security of PuO_2 overland shipments on the French territory has come under increased scrutiny because of the awaited one-off shipment of about 140 kg of US-origin weapons-grade PuO_2. This shipment, the Eurofab program,[9] is to be imported into France via the port of Cherbourg,[10] it will then be transported to the fuel fabrication plant at Cadarache for conversion to Mixed Oxide Fuel (MOX). Thereafter, the MOX fuel assemblies are to be returned to the United States, again via the port of Cherbourg. The sea and overland journey legs of the incoming US plutonium will be in FS47 casks and the return of the MOX lead test assemblies (LTAs) by FS65 casks.

Considerable controversy has arisen because of the dichotomous or double-standard approach of the US for the road transportation of the PuO_2 consignments when in transit in the United States when compared to the protection and security arrangements when in transit in France.

This is because, on one hand, the overland leg of road transport in the United States is to strictly conform to US Federal requirements[11] for a single and exceptional shipment of weapons-grade PuO_2 that it defines to be *"strategic special nuclear material"*[12] requiring *"that the transport methods to be employed . . . afford security against sabotage or terrorism, as well as safety in the event of an accident"*, and where the additional safeguard of the *"Stored [nuclear] Weapons Standard"* is to be deployed. For this US road transport phase the US DOE has undertaken an exhaustive hazard and risk assessment, including an evaluation of the consequences of a release of plutonium during or following an incident that severely damages one or more of the plutonium carrying FS47 casks.[13]

On the other hand, and quite to the contrary, the US DOE has completely entrusted the nuclear safety, protection and security aspects for the transportation through France to the French authorities. In fact, no indication has been made public that the transportation arrangements and safeguards applied by the French competent authorities will significantly differ from those in place for the existing French-origin react-grade PuO_2 consignments.[14]

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9 See US DOE, *Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement (Storage and Disposition PEIS)* DOE/EIS-0229, December 1996; also US DOE, *Surplus Plutonium Disposition Environmental Impact Statement (SPD EIS),* DOE/EIS 0283, November 1999.

10 The actual date of this arrival is unknown at this time, the estimated arrival in the French port is expected to be late-September to mid-October, 2004.

11 These duties have been detailed in the DOE submissions on the plutonium disposition programme.

12 The Code of Federal Regulations, Part 73, S73.1 and 73.2 defines this to be more than 5kg of U-235 enriched to 20% or more and/or 2.5kg or more of plutonium.

13 US DOE, *Supplement Analysis, Fabrication of Mixed Oxide Fuel Lead Assemblies in Europe*, November 2003, DOE/EIS-0229-SA3.

14 See J. H. Large, Y. Marignac, *IAEA Requirements on Design Basis Threat Assessment - Non Compliance of Eurofab Shipment from US to France on UK Vessel: Security and Physical Protection Issues*, Submission to the International Atomic Energy Agency, 20 September 2004.

APPROACH OF FRENCH AUTHORITIES

The French competent authorities for the safety and security of the plutonium transports are respectively the French safety authority, the *Direction générale de la sûreté nucléaire et de la radioprotection* (DGSNR), and the High Civil Servant for Defence in the Minister of Industry, the *Haut Fonctionnaire de Défense* (HFD). Both rely, for the assessment of the risk and the adequacy of the measures, on the technical support provided by the IRSN.

In summary, the French approach is based on the combination of two essential principles, first it is claimed:

- that the containment performance of the FS47 cask when subjected to the IAEA specified TS-R-1 accident conditions demonstrates that the cask is also robust enough to cope with all possible situations arising from malevolent external acts (i.e. terrorism and/or sabotage).

This is quite misleading because the prescribed IAEA tests are based on 'credible' or reference accident conditions, which have been previously determined in severity on a probabilistic forecast of risk, whereas a terrorist attack would be expected to be dominated by elements of intent and intelligence so probability cannot be usefully applied. Although the FS47 cask is certified in accord with the IAEA 1996 regulations,[15] this certification does not relate the cask performance when subject to possibly extreme circumstances and forces from intentional (non PRA) terrorist acts.

Second:

- the foregoing first principle is on the proviso that it is possible to prevent the threat of acts of terrorism, notably through a policy of secrecy on the routes and timetable of the plutonium transport runs.

Very little of the French approach to security and physical protection of nuclear materials in transit (or at fixed nuclear installations) is available in the public domain, although some insights have been provided in the recent years by authoritative seminar papers by IRSN.[16]

As acknowledged by IRSN in a recent paper summarizing *"the French approach concerning the protection of shipping casks against terrorism"*,[17] there exist no formalised regulatory requirements in France regarding the security of the casks beyond the accident prescription of the IAEA test. Contrary to requirements applying to the operators of fixed nuclear facilities, *"there is no legal framework allowing the competent authority to require that the transporters or designers of packages perform the assessments of the casks behaviour in such situations"*, although this appears to be opposing IAEA requirements for the physical protection of the transport of nuclear materials.[14]

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[15] Type B(U) in accordance with IAEA 1996 Regulations, TS-R-1 – see also *Regulations for the Safe Transport of Radioactive Material, Safety Standards Series No. ST-l* Requirements, Edition, Vienna (1996)

[16] Notably:
- P. Cornu, et al *Protection of Nuclear Facilities and Nuclear Materials Against Malevolent Actions*, EUROSAFE 2001, Seminar 5 Nuclear Material Security. http://www.eurosafe-forum.org/down2001/semb5_3.doc
- R. Vernot, et al, *Physical Protection, Accountancy and Control Systems Vulnerability Assessments*, EUROSAFE 2002, Seminar 5 Nuclear Material Security. http://www.eurosafe-forum.org/ipsn/pdf/euro2_5_5_physical_protection.pdf
- J. Aurelle, et al, *Short and Medium Term Consequences of the 11th September Attacks on Physical Protection Activities in France*, EUROSAFE 2002, Seminar 5 Nuclear Material Security. http://www.eurosafe-forum.org/ipsn/pdf/euro2_5_2_consequences_france.pdf

[17] B. Autrusson, D. Brochard, "The French approach concerning the protection of shipping casks against terrorism", paper from a presentation given in *ASME Pressure Vessels and piping*, Cleveland (USA), 21-24 July 2003. http://www.irsn.fr/net-science/liblocal/docs/docs_DEND/frenchapproach.pdf

In effect, this confirms that the FS47 cask design has been 'assessed' and certified compliant solely on the basis of accord with the safety requirements developed for probabilistically acceptable (i.e. credible) accident situations. It follows and it is most likely that the FS47, the design of which was developed in the early 1980s,[18] has been certified and put into service without considering its robustness against any specific malevolent acts whatsoever. The IRSN admit as much in that it considers *"in order to provide the Authority with elements of appreciation, has conducted analyses based on both experimentation and numerical modelling for various kinds of casks and loads, for the last ten years"*, being motivated by its concern that *"the potentiality of such an aggression exists and considering the number of shipments organized every year"*.[17]

However, this *'appreciation'* programme, which includes elements of fire and explosive performance of the FS47, still does not include transport-terrorist-specific requirements against which to trial the cask design. Instead, the IRSN draws its approach for assessing the security of the transport casks on that in force regarding fixed nuclear plants.[19] Also, according to the IRSN, *"the procedure to evaluate the consequences of terrorism against facilities requires two stages. The first one is the sensitivity study which aims to determine what could be the consequences (...). The second stage is the vulnerability assessment which aims to quantify the difficulty to perform the aggression"*.

In the French regulatory framework, which *"lays down a performance-based approach rather than a compliance-based approach"*, it is mostly vulnerability that is assessed in specific security studies – those not being applied to the transports.[20] The *"analysis of the sensitivity involves using safety analyses to identify potential accident sequences"*, and is performed *"mainly by using a standard incident or accident list taken into consideration at the facility design stage"*[21] or, for transport, the cask and vehicle design. In addition, regarding the objectives of physical protection, *"acceptable consequences are taken as being those leading to levels of radioactive releases less than, or equal to, those taken into account in the facility safety case. . . ."*.[17]

This consequence-driven approach might, if drawn towards the larger amounts of plutonium in store rather than the smaller quantities under transportation at any one time, be at the sacrifice of properly scrutinising the potential for a higher frequency of accident and the greater vulnerability to terrorist attack of plutonium consignments in transit.[22] Indeed, a transposition of the combined sensitivity and vulnerability approach to the transportation arrangements indicates a potential for higher, or at least comparable risk frequency, than those applied to fixed plutonium facilities. In particular, the lower level of protection (mainly those offered by the FS47 cask itself - Figure 1), and the higher level of vulnerability and risk (the very much larger number of opportunities

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[18] Then by the COGEMA subsidiary Transnucléaire (now COGEMA Logistics).

[19] As stated by IRSN, *op.cit.*, *"for the nuclear facilities, the French regulations state that the consequences of aggressions aiming at generating a safety hazard and/or radiological releases in the environment must be assessed* [and] *have to be evaluated in terms of safety, of pollution in the environment and of radiological consequences for the population"*.

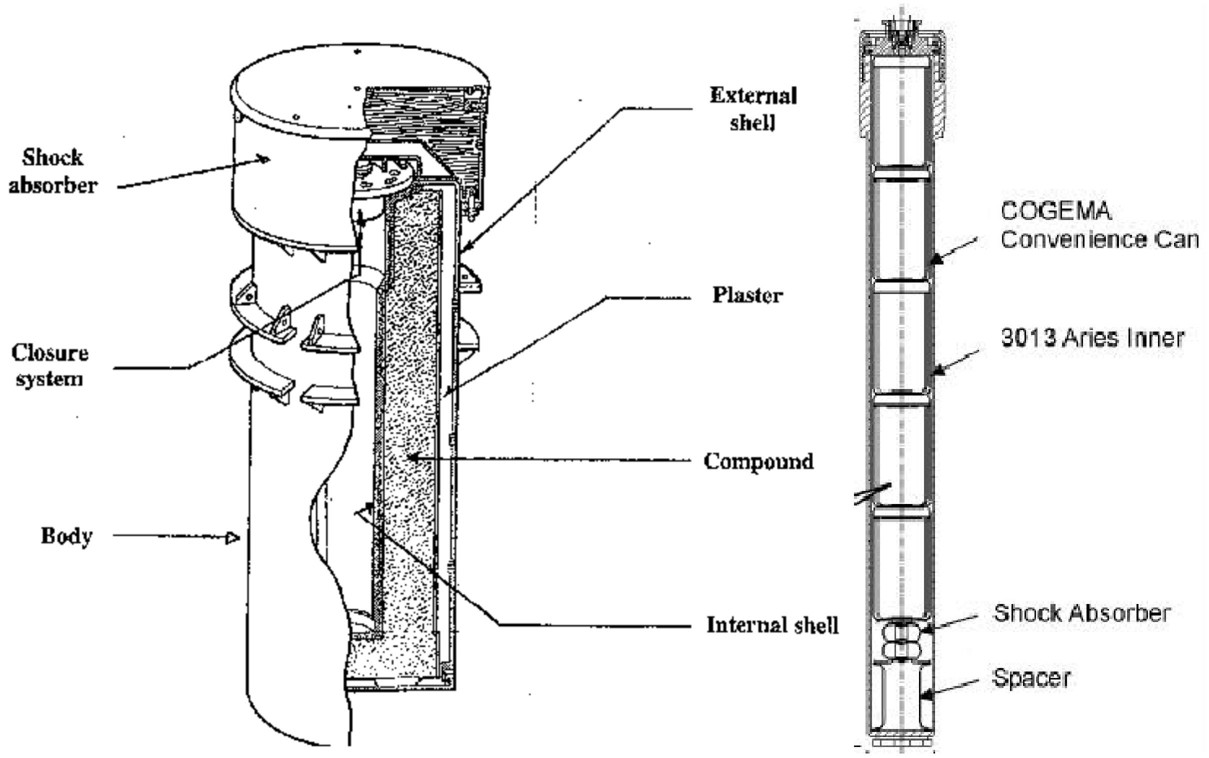
[20] R. Vernot, et al, *op. cit.*

[21] J. Aurelle, et al, *op. cit.*

[22] For example, the quantities of plutonium concerned by nuclear transports are of course less than those currently stored in MOX facilities such as the Cadarache ATPu where the LTAs are to be fabricated. However, if the ATPu fabricated around 2.5 t of plutonium into MOX fuel every year, it is likely than at any time around 1 to 1.5 t of plutonium dioxide feedstock would be present in the facility. This feedstock can be compared to the roughly 150 kg of plutonium transported by a single truck, which cannot reasonably provide the same defence in depth safeguards whilst journeying on public roads against terrorist acts (or sabotage) than the feedstock plutonium secured in storage cells of the Cadarache facility. Moreover, whereas the range of potential hazards and threats to the feedstock plutonium secured at Cadarache may be identified with a high degree of certainty (i.e. aircraft impact, truck bomb, armed insurgent group, etc), the range of potential hazards for a plutonium consignment is very much broader, so varied in fact as to be virtually impossible to exhaustively identify and safeguard against.

available over the publicly accessible transportation route), explain why the secrecy of the transport (routes and counter-measures equipping the vehicles and trailers) is a key feature and mainstay of the French security approach.

Figure 1: **Drawing of the FS47 packaging (left) and its inner AA227 container containing up to five AA432 boxes (right)**



Source : DGSNR, 2003; DOE, 2003

THE SECRECY POLICY

The secrecy enveloping the PuO_2 transports has been regularly breached by Greenpeace (France) in recent years. Based on public information, mainly by on-the-ground observation of the routes and days of transports, this environmental organisation has and continues to reveal serious flaws in the security arrangements of the plutonium convoys, with Greenpeace being able to predict dates, times and routes being used by the plutonium convoy, some of which could be readily obtained from publicly available sources.[23] On one occasion, on 19 February 2003, Greenpeace activists intercepted and immobilised for a few hours a truck transporting about 150 kg of plutonium in the town centre of Chalon-sur-Saône.

In response to the Greenpeace exposé, French authorities introduced a highly controversial decree[24] censoring, under the law on national defence secrecy, the holding and release of any information concerning the conditions of storage, manipulation, or transport of nuclear materials. Following strong political and public opposition, a more specific version was enacted in January 2004,

[23] See: http://www.stop-plutonium.org

[24] Arrêté du 24 juillet 2003 relatif à la protection du secret de la défense nationale dans le domaine de la protection et du contrôle des matières nucléaires, *Journal Officiel*, n° 183, 9 August 2003, p. 13859. http://www.legifrance.gouv.fr/WAspad/UnTexteDeJorf?numjo=INDI0301765A

although still ambiguous definition of the information to be classified secret,[25] with this being accompanied by a less than explanatory circular.[26] Regarding the classification of information on transports, the decree clearly stipulates that secrecy specifically applies to the nuclear materials defined as *Category I* [27] and to unirradiated materials of *Category II*, which in accordance with the French application of IAEA categories, targets the transports of separated plutonium and of unirradiated MOX fuel. This is made necessary while, *"considering the current level of existing threats"*, there is no need to classify information related to other transports of nuclear materials (irradiated materials under *Category II* and all kind of materials of *Category III*). This 'defence secrecy' decree is still being contested on judicial grounds by various concerned organisations, including WISE-Paris.[28]

However, as continued action by Greenpeace, including on-line and real-time information on ongoing plutonium shipments,[29] has shown that such classification can hardly guarantee secrecy when the transportation convoys are so easily identified on the public highway. Put another way, if the environmental organisation Greenpeace is able to readily identify and locate in advance the plutonium convoys, then there is nothing to bar other, less benevolent and non-peaceful organisations from doing much the same. In other words, the 'defence secrecy' decree is totally ineffective in this matter.

POTENTIAL FOR A CATASTROPHIC EVENT

The physical and thermal response of the FS47 cask when subject to a number of contrived, although not necessarily the most damaging situations, together with the projected release fractions of the plutonium consignment and the consequences of this, have been analysed, projected and discussed in a series of publications.

Several studies have challenged the official safety and security assessment of the plutonium transports in France. In particular, separate studies commissioned by Greenpeace (France) and Greenpeace International enabled the French independent agency WISE-Paris[30] and the UK-based consultants Large & Associates,[31] to each identify much the same shortcomings of the French

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[25] Arrêté du 26 janvier 2004 relatif à la protection du secret de la défense nationale dans le domaine de la protection et du contrôle des matières nucléaires pris pour l'application du décret n° 98-608 du 17 juillet 1998 relatif à la protection des secrets de la défense nationale, *Journal Officiel*, n° 24, 29 January 2004, p. 2092.
http://www.legifrance.gouv.fr/WAspad/UnTexteDeJorf?numjo=INDI0402369A

[26] Circulaire du 26 janvier 2004 prise pour l'application de l'arrêté du 26 janvier 2004 relatif à la protection du secret de la défense nationale dans le domaine de la protection et du contrôle des matières nucléaires, *Journal Officiel*, n° 24, 29 January 2004, p. 2098 - author, the Haut-fonctionnaire de défense (high civil servant for defence matters) of the Ministry of industry, Didier Lallemand..
http://www.legifrance.gouv.fr/WAspad/UnTexteDeJorf?numjo=INDI0402369C

[27] IAEA INFCIRC/225/Rev 4.

[28] Several requests against the first and second version of the "Arrêté" have been presented to the Conseil d'Etat, notably by an environmental organisation (Greenpeace), independent information and expert agencies (CRII-Rad, WISE-Paris), and a journalists association (Reporters sans frontières).

[29] See for instance details on Greenpeace "Stop-Plutonium" web site about a transport on 31 August and 1st September 2004.

[30] Y. Marignac (Dir.), X. Coeytaux, M. Schneider & al., *Les transports de l'industrie du plutonium en France : une activité à haut risque*, WISE-Paris, February 2003.
English summary: http://www.wise-paris.org/english/reports/030219TransPuMAJ-Summary.pdf
Report, in French only: http://www.wise-paris.org/francais/rapports/transportpu/030219TransPuRapport.pdf
Appendices: http://www.wise-paris.org/francais/rapports/transportpu/030219TransPuRapport_Annexes.pdf

[31] Large & Associates, *Potential Radiological Impact and Consequences Arising from Incidents Involving a Consignment of Plutonium Dioxide under Transit from COGEMA La Hague to Marcoule/Cadarache*, R3108-A6, 2 March 2004.
http://www.greenpeace.org/international_en/multimedia/download/1/424600/0/Large_report.pdf

system of plutonium transportation. In a highly unusual move, IRSN responded publicly by posting on its website a brief rebuttal that strongly denied the critical findings and conclusions of the two reports.[32]

However, the IRSN rebuttal itself failed to refer to and account for previous IRSN research on the integrity of the FS47 cask that acknowledge features of the design that enable (via cask failure) very significant plutonium releases.[33]

First, the substantive findings of both the WISE-Paris and Large & Associates studies are as follows:

WISE-Paris Report: The WISE-Paris report, which builds on a previous study of 1995,[34] arrived at the following summarised finding:

- The number of French-sourced PuO_2 transports over a typical or representative year,[35] is 89 or so consignments covering a cumulative distance of around 250,000 km per year.
- That it is relatively straightforward to match the plutonium movement data to the available road accident statistics and known hazards along the transport routes, such as the rate of vehicles impacts, fires, etc., and the location of high bridges, viaducts, tunnels, etc.
- It was shown that the FS47 cask, as certified compliant with the IAEA transportation regulations,[36] would not survive with its surety intact under the conditions encountered in 1 in 20 real road accidents (half of which involve severe fire) occurring on the French road system.
- Thus, the *"mechanical and thermal design of the FS47 transport package is minimal, or even inadequate"*, with this being illustrated by evaluation of cask performance when subject to realistic scenarios, including an impact-fire involving a hydrocarbon road tanker, and a terrorist act involving an armour-piercing artillery round/RPG projectile.
- Scoping analysis projected radiological consequences for an incident nearby the northern suburb of Lyon, the impact-fire road accident involved upwards of 6,000 people with several tens of fatal cancers and for the terrorist attack, the at risk of 125,000 people over a 250 km^2 area, with a consequence of 500 fatal cancers developing in the interim- and longer terms.

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32 IRSN, *Risques de rejet radioactif lors du transport routier de poudre d'oxyde de plutonium en colis FS47*, not dated (March/April 2004). http://www.irsn.fr/vf/05_inf/05_inf_1dossiers/05_inf_35_pu/05_inf_35_pu.shtm

33 B. Autrusson, D. Brochard, *op. cit.*

34 M. Pavageau, J. Hazemann & M. Schneider, *Les transports de l'industrie du plutonium en France*, WISE-Paris, October 1995.

35 The representative year derived from a total of around 450 consignments, that is a cumulative transport of 39 tonnes of plutonium dioxide powder over a 5 year+ period.

36 IAEA 1996 Regulations, TS-R-1 which specify that the design basis of the transport casks, including the FS47 cask, as required from the French regulation, itself derived from the International Atomic Energy Agency safety standards, is driven by safety considerations of withstanding mechanical shocks and fire conditions, as could arise from an accident. The safety requirements for the FS47 guarantee the cask's resistance in the following conditions:
- a 9 meter drop onto an unyielding surface and a one meter drop onto a steel spike;
- an engulfing fire for 30 minutes at 800°C;
- immersion under a head of water of at least 0.9 m during 8 hours;

and, not applying to the overland transports but still relevant for the overseas part of the journey in the case of the US plutonium shipment:
- immersion under a head of water of 200 m during at least one hour.

- Recommended that *"it would be desirable for the competent authorities – such as the Institut de radioprotection et de sûreté nucléaire (IRSN) – to enhance their technical support with detailed calculations of this type of accident (…), the results of [which] should be made public"*.

The WISE-Paris report also identified the lack of information and inadequacy of emergency preparedness of the local authorities along and nearby the plutonium road routes from la Hague to Cadarache and Marcoule, noting that in the event of an incident the public would be ill-prepared to implement even the most basic self-protective actions during the immediate aftermath of the radioactive release.

Large & Associates Report: This study concentrated specifically on the risks associated to *"the road haulage of consignments of PuO_2 from the COGEMA reprocessing plant at la Hague near Cherbourg to the mixed oxide fuel fabrication plants at Cadarache and Marcoule in southeast France"*, and it incorporated the primary issues of the Large & Associates evidence[37] to the US NRC hearings for the export of plutonium to France (Eurofab program), with its summarised findings as follows:

- As a reference assumption of the release in case of a cask failure, Large & Associates adopt the release fraction determined by US DOE Eurofab study[38] prepared for its projected plutonium transfer to France, this being equal to 595 g of respirable-sized aerosol (or 3.5% of the content of the failing cask), applying this to a French sourced, 9 casks per vehicle, consignment of reactor-grade PuO_2 .
- This release fraction is applied for the incident scenarios of (i) a severely damaging road accident in which one FS47 cask is breached, (ii) a similar road accident where three FS47 casks fail in a single vehicle (to take account of the difference between the DOE analysis of a three FS47 consignment in one truck, and the practice of the French transports where each truck conveys nine FS47); (iii) a road incident in which both vehicles of the convoy are entrapped in a severe road tunnel fire in which all casks fail (that is, eighteen casks), and (iv) a well planned and executed terrorist attack centred on one of the two vehicles (with nine casks failing).
- The probability (frequency) of each accident scenario is determined, using a US model, to be *"the probability of a collision-with-truck-or-bus event at a velocity of, say, 80 kph followed by impact with an unyielding object (i.e. a bridge abutment) and then a high-temperature engulfing fire of 2.0 to 3.0 hours duration is 6.06E-07"*, or a risk of 1 out of 1.6 million and, for the terrorist scenario, the probability reason is disqualified as inapplicable and the risk considered to be that of mathematical eventuality.

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37 J. H. Large, 1) Disposition of Surplus Weapons Plutonium Using Mixed Oxide Fuel – *Comments on Opinion on the Applicability and Sufficiency of the Safety, Security and Environmental Requirements and Measures as these Apply to the Transatlantic Shipment, European Waters and France*, 2) *The Role of PNTL Ships in the Atlantic Transit Phases*, United States of America Nuclear Regulatory Commission, 26 November 2003, 3) *Summary of the Findings of the French-sourced Plutonium Dioxide Transportation*, 23 March 2004 – US Nuclear Regulatory Commission Hearing, 2004.

38 Successive documents assessing the FS47 safety in the framework of the plutonium transports required for the MOX program of the US surplus plutonium disposition plan include the following filings to the NRC:
- Department of Energy, *Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement (Storage and Disposition PEIS)*, DOE/EIS-0229, December 1996;
- Department of Energy, *Surplus Plutonium Disposition Environmental Impact Statement (SPD EIS)*, DOE/EIS-0283, November 1999;
- Department of Energy, *Supplement Analysis, Fabrication of Mixed Oxide Fuel Lead Assemblies in Europe*, DOE/EIS-0229-SA3, November 2003.

- Using reference computer models,[39] seeded with actual meteorological, geographical and population data for the two localities considered (near Paris and Lyon) and which incorporate mitigation from reasonable levels of countermeasures, the range of probabilities projects interim and late mortality numbers extremis of 34 to 1,323 for the mean mortality, and 523 to 11,520 for the maximum mortality, the highest incidence resulting from the tunnel fire road accident.
- In the terrorist triggered release scenario, the numbers of public requiring to shelter, around Paris for example, ranges from some 40,000 to several million individuals over an area of up to 900 km^2, and relocation zones could extend out to 15 km from the centre of the incident.

Large & Associates had also submitted three sets of evidence[37] to the US DOE hearing considering the export licence for US weapons-grade plutonium to France (Eurofab) thus enabling comparisons to be made between the respective approaches of the French and US authorities to nuclear safety and security, concluding *"using the same transport cask (FS47), the US restricts the number of casks per vehicle to 3, whereas the French transport up to 9 fully loaded casks per vehicle. The US road convoy comprises custom-built Safe Secure Transport (SST) trucks that are fully armoured and equipped with at least two systems that automatically prevent the removal of the casks and armoured personnel carriers accompany the convoy throughout its transit, whereas the French vehicle seem to be little more that a commercial tractor unit hauling a standard trailer with an ISO container attached, with the two consignment trucks making up the convoy being accompanied by 6 to 8 Gendarmerie travelling in what seem to be a standard and unarmoured minibus and a car"*, going on to note an incredible – and unexplained – gap in the assessment of cask surety when subject to accident conditions *"the US analysis reaches the conclusion that the FS47 cask could fail in a road accident and that there is a potential for 595 g release from each cask in transit which compares to the utter confidence of the French that the FS47 cask is failsafe, so much so that the worst credible accident would only result in a 0.07 g release"*.

IRSN REBUTTAL

The short statement published by the IRSN[40] in response to the WISE-Paris and Large & Associates individual studies generally dismisses their conclusions on the scale of the potential human consequences in the localities of the road routes; it confirms the IRSN assessment of 0.07 g to be the maximum release fraction of plutonium from a FS47 for which emergency response measures are planned; and it almost flippantly dismisses the US derived release fractions adopted for the Large & Associates analyses.

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[39] The dynamics of the developing plume concentration, dispersion and deposition fall-out are plotted using the NOAA HYSPLIT model, the USD Air resources Laboratory air concentration and dispersive model.
Plume rise prediction is by Hotspot, the Lawrence Livermore National Laboratory predictive software for release plumes.
The environmental impact, including human health consequences are modelled using COSYMA, the European Commission sponsored and approved nuclear accident assessment software modelling facility development of the MARIA (Methods for Assessing Radiological Impact of Accidents) code. The model adopts the universal assumption that the health risk is linear to radiation exposure and uses recommendations of the International Commission on Radiological Protection (ICRP) for morbidity and mortality factors and the use of the effective dose equivalent (EDE) method. For population numbers the COSYMA model data base is seeded with population census figures on a 10km^2 grid basis.

[40] IRSN, *op. cit.* Quotes in this section are translated from the French by WISE-Paris.

The IRSN statement falls far short of an effective rebuttal of the specific revelations of the two independent studies:

- IRSN does not comment on the inadequacies of the IAEA TS-R-1 test compliance requirements and how these fail to relate to real incidents, both accidents and potential terrorist acts, particularly the drop, spike penetration and thermal endurance tests.
- IRSN does not respond to the WISE-Paris findings on the inadequacy of safety requirements in view of the French road accident statistics and traffic conditions for the transport of hazardous material, nor does it give regard to the low but not inconsiderable probability of severely damaging accidents identified by Large & Associates.
- IRSN fails to adequately explain why it is reasonable for the US analysis to derive a much higher release fraction, as adopted by Large & Associates, when the plutonium is under road transit in the United States whereas, when in the same FS47 cask and in apparently less robust carrying vehicle, it (IRSN) is justified in reducing the worst case release fraction by a factor of ~8.500, down from the US 595g to 0.07g applied to the very same FS47 cask when in transit in France.

Instead IRSN concentrates on the margins between the (TS-R-1) regulatory safety requirements and what it claims to be the real limits of the FS47 mechanical and thermal resistance. For this reference is made assessments of the FS47 safety performance undertaken between 1994 and 2002. According to the findings of this programme, the FS47 design is claimed able to resist much more severe conditions than those required by the French (TS-R-1) regulations:

- *"it has been demonstrated that in case of impact under realistic accidental conditions (at 70 km/h on a range of metal targets and, impact at 113 km/h on reinforced concrete surface), there was not any plutonium oxide release"*;
- *"it has been determined by calculations that, for a drop height of 50 meter* [on a reinforced concrete surface], *the cask damage is comparable to those resulting from a 9 meter drop on an unyielding surface"*;
- depending on two types of sealing gasket material used, subject to a 800°C the surety lasts 5 h 30 min and around 10 hours, and for a 1,000°C fire 4 and 7 hours.

From these statements, IRSN arrives at the absolute conclusion *"that a transport accident cannot produce a breach in the cask"* and that *"the release of plutonium oxide in such an accident could only come from the loss of the sealing efficiency in the case of a long lasting fire, together with the degradation of the three inner containment barriers"*. The IRSN reasoning for this is that only a fraction of the small quantity of plutonium powder that might escape into the cask cavity would aerosolise and release if the cavity depressurised when the sealing gasket failed due to fire. IRSN evaluates this fraction at 0.07 g and nominates a worst case road accident scenario that could possibly result in this level of release, namely *"the crash of a FS47 carrying truck with a fuel tanker truck and a long lasting fire"* – which, the IRSN emphasises, *"covers the case of an accident occuring in a road tunnel"*.

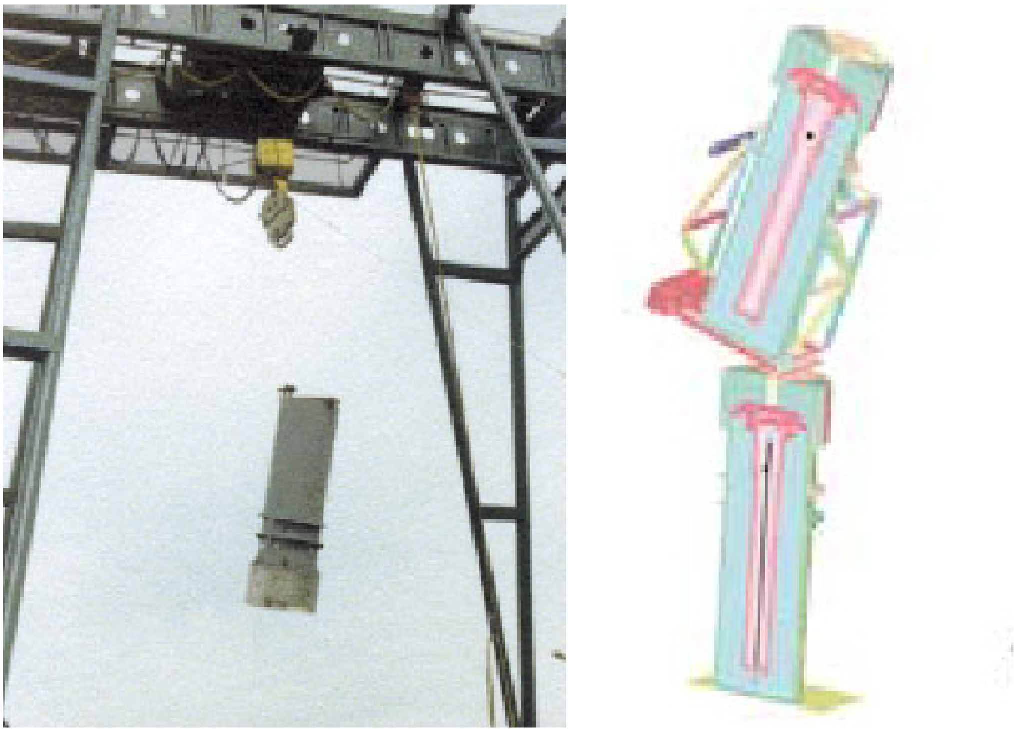
However, a little further examination of the past FS47 1994-2002 development/test programme shows IRSN's reasoning to be flawed because:

- The thermal studies conducted in the IRSN programme[41] comprise, apart from a single (actual) thermal test at 800°C for 3 hours 25 minutes conducted in 1993, entirely numerical simulations.

[41] The research programs on mechanical and thermal performance of FS47 that are the basis to the IRSN statement are respectively described and commented in:
• R. Vallée, L. Piot, "Simulations du comportement mécanique de colis de transport de matières radioactives sur cibles

- Thus, the IRSN conclusions on the FS47 thermal behaviour at higher temperature and longer fire duration have been extrapolated from a single test at less severe conditions – a methodology that is accompanied by great inherent uncertainty.
- Similarly, for the impact performance assessment of a FS47 falling from 16 m, in slanting position, onto a second FS47 in vertical position (Figure 2), the IRSN notes that *"the upper part of the closure system is impacted, but the computer model used is not precise enough to allow for assessing the damage and determining a potential loss of structural containment"*.[42]

Figure 2: Real scale drop test (left) and computer simulation (right) to assess the FS47 behaviour in potential handling accidents



Source : DSIN, 2001; IRSN, 2002

Impact Performance: So far as simulating real accident and terrorist incident conditions, the IRSN tests and modelled simulations are somewhat contrived. For example, IRSN does not consider fully perforating impacts; the impact simulations are applied to longitudinal impacts with a vertical descent of the cask, with no induced rotation, and the impacts always involved cushioning by the shock absorber end-cap.

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réelles", in *apport scientifique et technique IRSN, 2002*, IRSN, December 2002, pp. 102-108.
http://www.irsn.org/net-science/liblocal/docs/docs_DIR/RST2002/Chap03_art1.pdf

- F. Chalon, M. Héritier, B. Duret, "Numerical Study of the Thermal Behaviour of Packages Subjected to Fires of Long Duration", in *Proceedings, PATRAM'98, 12th International Conference on the Packaging and Transportation of Radioactive Materials, Paris, 10-15 May 1998*, vol. 4, pp. 1773-1780.

Additionnal information can be found in:

- S. Felix, F. Chalon & al, "Safety margins for radioactive material transport packages subject to fire: experimental work-development of numerical simulation tools", in *Rapport scientifique et technique IRSN, 2000*, IRSN, December 2000, pp. 87-93.
http://www.irsn.fr/vf/09_int/09_int_3_lib/pdf/rst2000/087-93.PDF

[42] R. Vallée, L. Piot, *op. cit.* Translated from French by WISE-Paris.

The general theme of past IRSN test and modelling programmes clearly relates to handling mishaps, particularly during craneage, and not to road traffic accident situations in which the force circumstance are likely to be more complex and of higher magnitude. In particular, the performance of a group of casks when racked for transport (Figure 3) under transverse impact has not been determined at all.

Figure 3: A plutonium shipment of 10 FS47 casks in vertical position in a rack, and its loadingin an unarmoured truck, as commonly practiced in France

Source : DSIN, 2001

Impact/Fire Performance: A significant omission in the performance assessment of the IRSN programme is where an impact damaged FS47 is engulfed in fire.

Although the IAEA Type B(U) compliance requirement requires the thermal test to follow the 9 m free drop impact test, IRSN skirts around this issue when claiming the FS47 cask is able to withstand more severe conditions, particularly mechanical damage and/or displacement of the inner thermal heat sinks and insulation, which is then engulfed in fire. As IRSN results demonstrate *"the thermal insulation effect brought by the compound and plaster protecting the content is significant"*,[43] which may be lost because of impact damage. In other words, the apparent impact fragility of the internal heat insulation system (gypsum plaster) may render such a damaged cask unsuited for subsequent fire engulfment of any significant duration, thus the severe impact-fire road accident scenarios identified by WISE-Paris and Large & Associates would present a serious threat to the surety of the FS47.

Another omission in the thermal testing that would, if accounted for, be more representative of real incidents is that the thermal tests and numerical simulations do not (apparently) account for radiant heat input from nearby surfaces (emissivity). This factor is important when the engulfing fire is located in a confined space such a tunnel (and which equally applies to the container of the

[43] F. Chalon, M. Héritier, B. Duret, *op. cit.*

plutonium truck) where temperatures can elevate very significantly above the hydrocarbon flame temperature (~880°C). Such elevated fire temperatures will also contribute significantly to plume lofting and the extent and area of the dispersion fall-out of the release fraction of plutonium, as modelled by Large & Associates.

Release Fraction: It is IRSN's resolution and stand on the 0.07 g release fraction that is so unsubstantiated.

The plainly obvious deficit of IRSN reasoning is why, when the plutonium is transported in batches of 9 or 10 casks in each vehicle, only one cask would fail thereby limiting the release its predetermined 0.07 g fraction. There is nothing in the IRSN rebuttal or in its published test programme that explains how tests or simulations on a single FS47 cask can be extrapolated to reason that a rack of 9 or 10 casks would sustain only one, albeit minor, cask failure.

In its rebuttal of the significantly larger release fraction adopted by the US DOE assessments IRSN declares that the 10% release fraction of NUREG-0170[44] to be invalid because the value is based on experiments conducted on casks much lighter than the FS47 in the 1970s that are not directly transposable and outdated. Actually, IRSN misunderstands or does not care to accept the US DOE adoption of the lower 3.5% release fraction used in its road accident scenarios[45] (as also applied by Large & Associates)[46] albeit that this US DOE fraction is x8,500 larger than the IRSN 0.07 g postulated release and, particularly, that the US DOE study of 2003 is more recent that the latest IRSN work in this area.

FS47 Proof Against Terrorist Acts: Until very recently, the main thrust of the French approach to counterterrorism for the plutonium transports seemed to be confined to maintaining secret the times and routes of the convoys, although this has been proved to be wholly ineffective by the publicity given to the transports by Greenpeace.

However, it now transpires that the *"French approach concerning the protection of shipping casks against terrorism"* (made public only a few months past),[47] had involved tests and trials that *"though not explicitly required in the French regulations, the security of the casks must be studied in the context of potential loads resulting from terrorism"*.

For this research, *"in 1996, IRSN has initiated a program concerning [the] FS47, used for the shipment of PuO_2 powder loaded by the detonation of a large amount of explosive"*. It comprised some earlier

44 NRC, *Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes*, NUREG-0170, December 1977.

45 The ignorance of the basis of the most recent US DOE assessment was already demonstrated in dismissing comments of the French safety authority at the time of Large & Associates' report publication, in March 2003. For instance, *"Jacques Aguilar, director for fuel cycle and transport at nuclear regulatory agency DGSNR, said the 595 g release contained in the DOE EIS and assumed by Large was based on an 'empirical or envelope value' for release coefficient specified in a 1977 document, never updated"*, quoted in "Greenpeace: Pu shipments vulnerable; Cogema, French official disagree", *Nuclear Fuel*, vol. 29, n° 6, 15 March 2004.

46 Actually, contrary to IRSN's assertion, Large & Associates do not deploy the NUREG-0170 10% release fraction other than coincidentally for the extreme scenario of a terrorist attack with the plutonium vehicle entrapped in a road tunnel where the casks are opened by explosive charges and then subject to an engulfing fire.

47 B. Autrusson, D. Brochard, *op. cit.* Although this paper may have been available to the 2003 Chicago conference delegates as of January 2004, it was definitely placed in public access through the IRSN web site on or about 23 February 2004.

IRSN reduced-scale tests on the explosive impact of explosive charges placed against the FS47 outer shell and, more recently, a series of numerical simulations.

- The explosive tests comprised detonation of *"a large amount of explosive (several hundred kilograms)"* [48] very close to reduced-scale mock-ups of FS47 casks – in these tests the outer cylinder and copper heat transfer shell were severely damaged being virtually destroyed, with the inner jacket being deformed.
- Data from the explosive tests was used to mount numerical simulations.
- The reduced-scale tests also included a mock-up of the vehicle trailer side walls with *"the trailers walls [which] are simulated by a two-layer aluminium sheet"* which seems to be consistent with the use of a standard commercial ISO container instead of a specially armoured container, but this scaled sidewall added little to the overall resistance in that *"the presence of the wall induces a delay in attack of the external shell of the mock-up, but its influence on the shock propagation velocity and the maximal pressure remains limited"*.

The damage sustained by the FS47 components is shown by Figure 4.

Figure 4: Exemple of the impact of an explosive device on the intermediate copper shell (left) and the inner container (right) of a FS47

Source : IRSN, 2003

At best, these explosive trials represent an explosive pack being placed on the outside surface of a free-standing FS47 cask, whereas in a real shipment each cask would be restrained by the vehicle rack frame, with the absence of this cask restraint attracting criticism because it *"would likely increase the equivalent plastic deformation of the inner tube locally to beyond its ductility threshold, bringing it to failure"*,[49] which, to an extent, IRSN acknowledges in that *"two additional tests have been scheduled to investigate the behaviour of the cask plug and the influence of the shipment configuration"*, although a seemingly unrepentant, IRSN concludes *"the central stainless-steel cylinder would not rupture"*, as under the conditions of experiments and tests *"the maximum equivalent plastic deformation does not exceed 14% whereas the ductility threshold is close to 32%"*.

Large & Associates suggest that a reasonable expectation is that a relatively advanced terrorist attack would deploy shaped charges, perhaps inside the cask outer shell that had been opened by

[48] It is unclear if the test endeavoured to simulate a 'home made' (nitrate rich fertiliser bomb); the explosive power would have been better expressed in terms of TNT equivalent.

[49] J. H. Large, *2nd Supplemental Declaration of 23 March 2004 of John H. Large in Support of Petitioners' Hearing Request and Petition to Intervene*, Declaration before the NRC, 23 March 2004.

thermic lance or a similar cutting device, or that a relatively advanced munitions with piercing or jetting capability would be used. This was trialled in the second series of test performed by IRSN by using a conically shaped charge to simulate a rocket propelled munitions: *"some years ago, IRSN has carried out tests on two FS47 casks filled with sand to simulate the PuO_2 powder, with a conical shaped charge (called CSC1) chosen on the basis of the availability, for the terrorists, of weapons with similar characteristics"* and, more recently, *"IRSN has undertaken the development of numerical models to identify and understand the physical phenomena involved in the interaction between the jet and the cask . . . also to estimate the consequences with a more efficient weapon called CSC2"*.[50]

There is far too little detail in the IRSN paper about the assumptions establishing the CSC2 munitions and no results whatsoever are given of the numerical modelling other than the comment *"these tests showed that the CSC1 passes through the first cask and slightly damages the second one without reaching its inner cylinder. An estimation of the quantity of nuclear material dragged out of the experimental device has been obtained . . . calculations with CSC2 have shown the increase of damage to the casks (mainly the second one) and justify the need for dedicated experiments"*.

The outcome of the numerical simulation of CSC1 are presented in Figure 5. Though difficult to interpret, they clearly indicate that a conical shaped charge projected against the cask perpendicular to its axis would penetrate the outer and intermediate shells, this jet passing through the inner cylinder and passing out the backside of the cask, therefore removing a volume of the plutonium oxide powder. Nevertheless, the IRSN paper introduces the caveat that *"the diameter of penetration is underestimated and the removal of nuclear material is overestimated by the calculation (the latter being related with the fact that the nuclear material removed from the inner cylinder may reach the outside)"*. So, according to IRSN logic, a larger breach in the side of the inner container results in less scavenging of PuO_2 from within – how odd !

The IRSN would not comment these results in account of the potential for future terrorist actions and, indeed, the whole approach of its programme is not to demonstrate the FS47 defeating design basis threat (DBT) scenarios[51] of nuclear transport, a definition of which does not exist in the French regulatory framework.[14] In fact, the basic conditions of IRSN explosive tests and simulations do not match the real conditions of realistic scenarios where many factors must be taken into account.[52] Without offering the basis for an assessment of the FS47 behaviour in such events, the IRSN conclusions nevertheless highlight the potential for plutonium diversion or dispersion scenarios.

In particular, by suggesting that a significant PuO_2 fraction could release from attack with armoured munitions, is contradictory with the principle set for the acceptability of the threat that the consequences of malevolent acts should not overcome, in terms of radioactivity releases, those taken into account in the safety case (based on accident events). In other words, the IRSN trials demonstrate that, contrary to IRSN's claim that the accident performance alone demonstrates the

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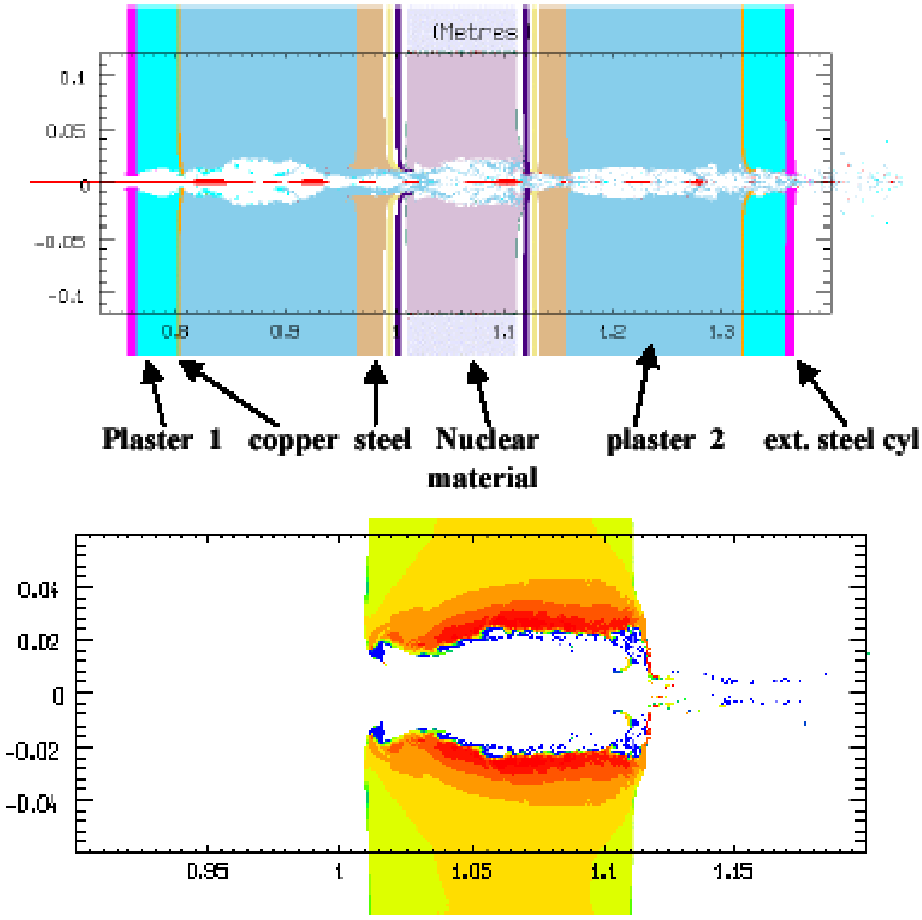
[50] IRSN do not indicate how CSC2 compares to a modern RP munitions but according to available specifications, modern missile launchers would hit fixed or mobile targets, within a few hundred meters range (the M-47 Dragon, for instance, has a shooting range of 800 m for 70 km/h vehicles) with missiles of 100 mm diameter or more at a speed above 200 m/s. These are able to penetrate 900 mm of armour.

[51] The Design Basis Threat, which the IAEA recommends to be defined by each State's Competent Authority as an essential tool of nuclear security, is defined in the French regulatory framework as *"the threat against which the licensee must be able to protect its facility"*. It comprises *"internal threats involving actions taken by insiders acting alone or not"* and *"external threats involving actions by small group of attackers"*, either *"a small team of attackers with limited resources"*, or *"a larger team with more sophisticated resources"* (in J. Aurelle, et al, *op. cit.*).

[52] For instance, *"internal threat has not been considered"* in the definition of the research programme, on the basis that *"such attackers don't have the tools fitted to damage significantly the cask"* (in B. Autrusson, et al, *op. cit.*).

robustness of the FS47 cask sufficient to cater for all terrorist incidents, show that the cask would fail and that the IAEA TR1 certification cannot at all be relied upon.

Figure 5: **Impact of a moderate efficiency conical shaped charge: penetration of the cask (above) and interaction with the nuclear material (below)**



Source : IRSN, 2003

Comments and Observations

After years of silence, recent observations and independent analyses have finally impelled IRSN to justify its approach to the surety and protection of PuO_2 under transit from la Hague to the plutonium fuel fabrication plants at Cadarache and Marcoule.

The IRSN retort, in the form of a negative rebuttal of the findings and recommendations of quite independent studies[30,31,37] and indisputable on-the-ground observations[23] is detached from and flies against the face of reality. In fact, the IRSN rebuttal raises more questions than it purports to answer and, similarly, recently accessible outline publications on past impact, thermal and explosive trials cast considerable doubt upon the validity of IRSN's development programmes for the FS47 cask design.

Putting aside the rebuttal of the analyses and findings of WISE-Paris and Large & Associates, the IRSN also rejects the FS47 cask design assessments undertaken by the United States DOE for its

Eurofab program. The outcome of the US studies is that, for overland transport in the United States:

- the PuO_2 consignments will be limited to 3 FS47 casks per special safe secure transport (SST) vehicle, whereas the French permit up to 9/10 FS47 per vehicle;
- that the worst case credible (road traffic accident) incident of the US analysis could give rise to a release in multiples of 595 g of respirable-sized for one, two or all the three casks carried, whereas the French limit the release to 0.07 g, apparently applied to just one cask out of a 9/10 cask vehicle load;
- that in addition to the IAEA225 requirements, whilst in the United States the PuO_2 has to be treated as a *strategic special nuclear material* for which the *Stored Nuclear Weapons Standard* has to be applied, whereas in France little distinction seems to be made (judging by the seemingly low level of security and protection given) to other transits of nuclear, although not necessarily highly fissile materials.
- That the United States opened its approach to security, protection and safety of its proposed transportation of PuO_2 to public consultation and inquiry, an openness that the French public have to forego because of French authority's commitment to secrecy.

It is, perhaps, continuing secrecy about the French-origin reactor-grade PuO_2 transports that is so disturbing: This secrecy provides little by way of any defence-in-depth against would-be terrorists gaining information about the dates and routes of the plutonium convoys, instead it serves as a barrier to the French authority's accountability and its justification for its present practises that it claims to fully protect the French public in these unsettled and dangerous times.