An Investigation into the Falsification of Pellet Diameter Data in the MOX Demonstration Facility at the BNFL Sellafield Site and the Effect of this on the Safety of MOX Fuel in Use

by

The Nuclear Installations Inspectorate of the HSE

FOREWORD

This report sets out the findings of the investigation carried out by HSE's Nuclear Installations Inspectorate into the falsification of quality assurance data associated with the production of MOX nuclear fuel pellets manufactured in the MOX Demonstration Facility at Sellafield.

The investigation was carried out under the control of the Deputy Chief Inspector responsible for regulating the safety at BNFL's sites. The investigation began shortly after BNFL notified NII of suspected falsification on 10 September.

It is the Executive's view that the report gives a thorough analysis of the issues surrounding the falsification of quality assurance data at MDF. It is clear that various individuals were engaged in falsification of important records but a systematic failure allowed it to happen.

It has not been possible to establish the motive for this falsification, but the poor ergonomic design of this part of the plant and the tedium of the job seem to have been contributory factors. The lack of adequate supervision has provided the opportunity. Despite this, self-discipline ought to have ensured that those involved followed the proper procedures.

One point worth noting is that in the new Sellafield MOX Plant, currently being commissioned, the inspection processes for MOX pellets, rods and assemblies are designed to be almost fully automated: this should prevent the falsification of data of the kind described in this report.

There are many lessons to learn, but the MOX Demonstration Facility is shut down and will not be allowed to restart until NII is satisfied that the recommendations in the report have been implemented.

If you have any comments, or would like further information on the issues discussed in this report, write to the Chief Inspector at the following address below:

Laurence Williams
Director of Nuclear Safety and HM Chief Inspector of Nuclear Installations
Health & Safety Executive
St Peter's House
Stanley Precinct
Bootle L20 3LZ

SUMMARY

The MOX Demonstration Facility (MDF) at BNFL's Sellafield site manufactures MOX (mixed oxides of plutonium and uranium) fuel pellets and assembles these using various customer supplied components to make complete fuel assemblies for use in nuclear power reactors. Each fuel pellet produced passes through a fully automated laser micrometer which checks and records the pellet's diameter at three points along its length, giving a 100% automatic check on all pellets used in a fuel rod. Any undersized or oversized pellets are automatically rejected. Those which fall within the specified diametral tolerance pass onto the next stage where each undergoes further visual checks. As a confirmatory check on diameter and in accordance with the 1% Acceptable Quality Level (AQL) criterion set out in BS 6001, a sample of 200 pellets (approximately 5%) which have passed through both these stages is measured for a second time. This quality check is done using a similar micrometer, but the sample pellets are presented to the micrometer by process workers who type each measured diameter, e.g. 8.195mm, into a computer spreadsheet.

On 20 August 1999 a member of MDF's Quality Control Team identified similarities between the secondary pellet diameter data for successive Lots. After further investigations, on 10 September 1999 BNFL reported to NII that some of these secondary pellet diameter checks on the fuel manufactured for a Japanese customer appeared to have been falsified by copying some data between spreadsheets.

The Health and Safety Executive's Nuclear Installations Inspectorate (NII) promptly launched an investigation to establish both the extent of the falsification and the causes of the event. NII concluded that data had indeed been falsified but that this would not affect the safety performance of the fuel, given the automated primary diameter check on 100% of the pellets used in each fuel rod.

NII believes the failure to properly carry out the agreed manual checks of the pellet diameter to be a contractual issue between BNFL and its customer. However, because it also represents a deliberate breach of operating procedures the Inspectorate launched an investigation which centred upon:

1. understanding just what had occurred in MDF and why;
2. whether the fuel involved will be safe in use; and
3. what needs to be done to prevent any recurrence.

NII's investigation into possible reasons for the falsification identified that although various individuals were at fault, a systematic failure allowed it to happen. In a plant with the proper safety culture, the events described in this report could not have happened.

NII commissioned an independent analysis by HSE's statisticians of the extent of the falsification. The results of this and further manual checks of data by NII showed that the initial investigation by BNFL, carried out under severe time pressures was too narrow: there had been a tendency to rush to early conclusions which understated the extent of the problem by assuming that the falsification was largely confined to one shift. Nevertheless BNFL agreed to carry out further, more detailed investigations and, following discussions with NII, has taken steps to address the contributory factors to this incident which the Company and the Inspectorate have identified.

NII is satisfied that in spite of the falsification of the quality assurance related data, the totality of the fuel manufacturing quality checks are such that the MOX fuel produced for Japan will be safe in use. With regard to MDF, the plant is shut down and will not be allowed to restart until NII is satisfied that the recommendations outlined in this report have been implemented to ensure, inter alia, that the deficiencies found in the quality checking process have been rectified, the management of the plant has been improved and plant operators have been either replaced or retrained to bring the safety culture in the plant up to the standard NII requires for a nuclear installation.

CONCLUSIONS

103. The events at MDF which have been revealed in the course of this investigation could not have occurred had there been a proper safety culture within this plant. It is clear that some process workers falsified records of the diameter of fuel pellets taken for QA sampling. One example of falsification has been found dating back to 1996. There can be no excuse for process workers not following procedures and deliberately falsifying records to avoid doing a tedious task. These people need to be identified and disciplined. However, the management on the plant allowed this to happen, and since it had been going on for over three years, must share responsibility.

104. Before NII will allow the restart of MDF, BNFL will need to address all the recommendations in the report to the Inspectorate's satisfaction.

1. INTRODUCTION

Circumstances Leading up to this Investigation

1. In September 1999 BNFL reported to NII that some of the secondary checks on mixed oxide (MOX) fuel pellet diameter in the MOX Demonstration Facility (MDF) at Sellafield had been falsified.

2. Non-compliance with Nuclear Site Licence requirements is a serious matter, especially the deliberate falsification of records. NII therefore mounted an investigation into the events at MDF. This report sets out how NII conducted the investigation, its findings and recommendations to ensure that such events will not be repeated in the future.

Objectives

3. The objectives of the NII investigation were to: determine if any falsification of QA records had occurred, and if so; determine the extent of the falsification; determine who was involved; determine why falsification happened; examine the adequacy of BNFL's own investigation; determine if the data falsification had prejudiced the ability of the fuel to be safe in use; and make recommendations to HM Chief Inspector on the requirements for BNFL to restart operations in MDF.

Methodology

4. The investigation was carried out following the normal procedures for an event on a nuclear licensed site. The Site Inspector responsible for the area of Sellafield which included MDF carried out the investigation, supported as necessary by specialist colleagues.

5. The first phase of the investigation looked at the MOX fuel production process, particularly the quality control and quality assurance procedures, to determine the ease with which data relating to the parameters governing the safety of the fuel in use could be falsified. The second phase was to carry out a statistical analysis of the fuel pellet diameter measurements used for the Acceptable Quality Level (AQL) checks for the fuel manufactured for supply to the Japanese electricity utility, Kansai Electric Power Co. This statistical analysis was carried out by HSE's Epidemiology and Medical Statistics Unit. The third phase involved Inspectors who visited the plant and interviewed the staff to determine the extent of their knowledge of the falsification of the QC records, why this had happened, and to gain a view on the adequacy of the Management of the plant and their control and supervision of operations.

6. In addition to these activities, the Inspectors looked at the adequacy of BNFL's own investigation. This was done to check that NII had a complete picture of events. It was also done to check the thoroughness of the BNFL investigation process to see if there were implications for other parts of the Sellafield site. Finally, NII specialists examined the BNFL case justifying the safety of fuel in use against the criteria normally used in the UK and the USA, particularly the effect of fuel pellet diameter variations.

7. The Site Inspector carried out most of the on-site interviews and co-ordinated the activities and input from NII's specialists.

Statistical Analysis

8. To help determine the extent of the fuel pellet diameter data falsification, NII commissioned an independent statistical analysis of the AQL data. BNFL supplied NII with both the AQL and the 100% automatic laser measurements of pellet diameter. (The process is described later in this report.) NII consulted HSE's Epidemiology and Medical Statistics Unit (EMSU) who did the analysis. The timescale for the analysis limited the types of possible data falsification for which it was possible to test: the intention was to determine whether falsification had taken place and to establish its extent.

9. EMSU identified three types of data copying which were worthy of study: copying a whole spreadsheet and replacing some data entries - falsification being detected by assessing the number of cell for cell matches between spreadsheets; copying whole rows of three data entries, ie. the three diameter readings for one pellet, within a spreadsheet - falsification being detected by counting the number of duplications of rows within each spreadsheet; other manipulation and invention of data - falsification being detected by internal checks within the sample spreadsheet and by external comparison with data on the population from which it was supposedly drawn.

10. Although the above approach was judged at the time to be the most fruitful based upon the information supplied by BNFL and from a priori reasoning, it was recognised that the analysis would not be exhaustive, and other methods of falsifying the data could have been used. Item (c) above was intended to cover such things as pure invention of pellet diameter data and some other forms of copying and manipulation of data from one spreadsheet to another. However HSE's statistical experts advised that for many of the more sophisticated forms of manipulation, it would be difficult to devise appropriate tests and virtually impossible to interpret the results.

2. MOX FUEL MANUFACTURE AT SELLAFIELD

History of MOX Fuel

11. UKAEA and BNFL have been producing MOX fuel at Sellafield for more than 30 years. Extensive development work on the manufacture of MOX fuel in support of the UK Fast Reactor development programme has been completed. Associated fuel irradiation programmes carried out in the Dounreay Materials Testing Reactor, the Dounreay Fast Reactor and the Prototype Fast Reactor (PFR) were used to assess the influence of fuel properties such as density, fuel form and chemical composition on irradiation performance. In addition, the compatibility of fuels with cladding materials and the influence of manufacturing variables on the reprocessing behaviour of high burn-up fuels was assessed. In support of these programmes, more than two tonnes of experimental MOX fuel and 18 tonnes of driver charge MOX fuel was produced by BNFL in the Sellafield production plant facilities. Approximately 98,000 MOX fuel pins were irradiated in PFR between 1974 and 1994. The initial burn-up target set for PFR was approximately 75GWd/t HM, but large numbers of the pins reached burn-up levels well in excess of this target. Over 2,400 pins successfully reached burn-ups in excess of approximately 150GWd/t HM and 12 pins reached the level of approx 240GWd/t HM without failure. This programme has demonstrated the high quality of the fuel manufacturing process.

12. Following the Government's decision in 1988 to end the fast reactor programme, UKAEA and BNFL decided to collaborate in the development of a process to develop the use of MOX fuel to recycle separated plutonium in light water reactors. BNFL developed a two-stage strategy which involved:

    1. the construction of a small-scale plant, MDF, to produce commercial quality fuel for irradiation in commercial reactors; and
    2. the construction of the much larger scale plant, SMP, for bulk fuel supply.

13. BNFL's MOX Demonstration Facility is located in B33 at Sellafield. The building was originally owned and operated by UKAEA to support the Dounreay Fast Reactor Project, providing the experimental fuel for the Prototype Fast Reactor. 14. A decision was taken to build MDF in B33 where ventilation and support services already existed for plutonium operations. Construction of MDF commenced in 1991. The plant was handed over for initial commissioning in late 1992 and uranium commissioning started in May 1993. Plutonium active commissioning commenced in late 1993. In April 1994 ownership and operation of the Facility transferred entirely to BNFL. 15. The first fuel assemblies manufactured were for a utility in Switzerland. In late 1995 the plant produced fuel to a different design which was manufactured throughout 1996 for a German utility. This was followed by further Swiss fuel campaigns during 1997. At the end of 1997, the plant began to manufacture fuel to a Japanese design, which was manufactured in two separate tranches until September 1999 when the falsification came to light.

MOX Fuel Production Process

16. The Mixed Oxide Fuel Demonstration Facility is used to manufacture Mixed Oxide fuel containing natural or depleted uranium dioxide (UO2) enriched with plutonium dioxide (PuO2) for use in Pressurised Water (PWR) reactors. All the manufacturing processes from mixing the UO2 and PuO2 powders up to the stage where the completed fuel pellets are inserted into Zircaloy cladding tubes take place inside gloveboxes: stores are provided for completed fuel rods and for fuel assemblies. Details of the various checks made through the production process to provide quality assurance of the important fuel characteristics are given in Appendix 2.

Fuel Pellet Production

17. Accurately weighed quantities of PuO2 and UO2 powders are milled together with additives to produce homogenised MOX powder. This is then tumbled in a spheroidiser to produce free flowing granules. There is provision for sampling these granules for off-line analysis if required. The granules are pressed into pellets and a sample is checked for density. The pellets are then sintered under reducing conditions to produce ceramic MOX fuel pellets. The ceramic pellets are ground to meet closely defined customers' specifications, then checked using an automatic inspection system for dimension and visually inspected for surface defects. Samples are taken for physical/chemical analysis. Fuel pellets which pass the tests are then transferred to a buffer store.

18. The Automatic Inspection System in the Pellet Inspection Glovebox uses a precision calibrated laser micrometer to take three separate diameter measurements of each and every pellet. Any pellet containing one or more out of specification results is automatically rejected by a gate mechanism. This is failsafe by design in that failure of any part of the measuring or gate control mechanism results in the gate remaining in the closed position. Out of specification or unmeasured pellets are thereby guaranteed to be ejected from the process stream. The specification range for pellet diameters for the Kansai contract is + 0.0125 mm. The claimed accuracy of the automatically measured diameters is + 0.002mm.

19. The Lot identity of fuel pellets received from the pellet production area of MDF is recorded on receipt at the in-line pellet store glovebox. The pellet store has the capacity to store up to ten cassettes of fuel located on trays.

20. Each pellet Lot typically consists of up to 4000 pellets. The pellets are transported/ stored in a cassette containing 13 trays. Visual inspection is carried out on every single pellet in the Lot (this is referred to as screening). A different operator from that involved in "screening" then carries out the secondary sample checks for visual defects.

21. The secondary sample check for diameter (known as "overinspection" for diameter) is also carried out. An approximately equal number of pellets is selected at random from each tray to give a total of 200 pellets. Each of these 200 pellets is then manually measured for diameter by placing them lengthwise on a "V" shaped block and measuring top, middle and bottom diameters using a calibrated laser micrometer (the measurement takes place inside a glovebox, with the pellets being manually positioned by one of the operators using tweezers). The micrometer readings are presented on an LED display outside the glovebox and the measurement readings

manually input to a spreadsheet specific to the Lot being measured, by a second operator using a computer adjacent to the glovebox. The overinspection for pellet diameter requires two operators and takes between 1.5 and 2 hours to complete.

22. 600 diameter readings in total are therefore recorded covering the 200 pellets which form the 5% sample out of each Lot of approximately 4000 pellets. The spreadsheet automatically highlights individual readings which are outside specification (i.e. too high or too low), and calculates the mean diameter for each pellet based on the top, middle and bottom readings. If the mean diameter is outside specification, then the pellet is automatically identified on the spreadsheet as a reject. The Lot will pass or fail depending on the number of rejects found. Under the normal criterion, the Lot will pass on five or less reject pellets but fail on six or more.

23. If a Lot fails diameter "overinspection" it is returned for 100% automatic diameter inspection followed by re-overinspection for diameter measurement. A tightened inspection regime is applied to any Lots which undergo such inspection for a second time. Such Lots are required to pass on three or less rejects, and fail on four or more rejects.

24. There is a third independent check of diameter as part of the density measurement, but this involves a smaller sample of 20 pellets.

25. Following additional visual and sample diameter checks on the pellets, and also when the Pu enrichment has been confirmed as being within specification, each cassette is 'released' from its store position and the pellets are fed forward from the cassette trays to form pellet sub-stacks in the stack make-up area of the pellet load glovebox. Several sub-stacks are required to fill each cladding tube.

Fuel Rod Production

26. The next stage, rod fabrication involves the loading of sub-stacks of fuel pellets into the cladding tubes and sealing and decontaminating the rods prior to inspection. Facilities for rod recovery and the reclamation of fuel from reject rods are also located in this area. All operations in rod fabrication are carried out in a series of interconnected and free-standing gloveboxes.

27. Pellets are loaded into each tube through a closely toleranced insert. This insert would itself prevent the loading of any significantly oversized pellets which had somehow bypassed the 100% automatic diameter check stage.

28. The sub-stacks of pellets are length checked and weighed prior to being manually loaded through the toleranced insert into the neck of the fuel rod. The space between the end of the pellet stack and the top of the rod, is measured (plenum length check) and pellets are added, as required, to make up the correct stack length.

29. A plenum spring is manually loaded into the fuel rod and the top end cap is fitted and welded into position.

30. The full rod is then filled with helium through a small hole in the end cap to a required pressure and the hole is welded closed.

31. After further visual checks, checks on sample rods to ensure the correct internal helium pressure, and checks for surface contamination, rods are transported six at a time to the Fuel Assembly Area for further inspection.

32. Trays of finished rods received from the Rod Fabrication Area are subjected to a helium mass spectrometry leak test. Each tray of six rods is placed in a vacuum chamber where the pressure is reduced to a pre-set level. The atmosphere is then analysed for the presence of helium. This sequence of operations is carried out automatically. In the event of a positive helium result, indicating a loss of integrity in a rod tube, the six rods are tested individually. Rejected rods are sent for reclamation or recovery. After leak testing, the rods are examined by X-radiography. The rod is laid on a strip of photographic film on a table and passed through an X-ray machine. The film is processed and used to examine girth and seal welds, to detect defective pellets, and to confirm the presence of the correct components. After this, a special detection system checks the enrichment of every pellet in each rod, and the results are recorded on a scan output.

33. Manual checks for rod straightness, length and diameter are then carried out. The only stage at which the operator has significant hands-on contact with the fuel rods is during the rod straightness check. This operation involved manually rolling the rod on a flat table and inserting feeler gauges under any revealed gaps, and a visual inspection for weld form, scratches and surface blemishes is also carried out.

34. Reject rods are returned to the rod reclamation glovebox for reworking, or pellet recovery as appropriate. Accepted rods are transferred on a shielded trolley to the rod store where they are loaded into magazines.

Quality Control / Quality Assurance Procedures

35. The fuel manufactured in MDF for commercial purposes is covered by Quality Control Plans which must be approved by the customer before fuel manufacture can begin. In this way, BNFL provides assurance that the fuel supplied will perform in reactor in accordance with the design specification. The quality control plan (amongst other things) defines for each characteristic the specific requirement, the method of analysis or measurement, the frequency of measurement and/or sampling, and how the information is recorded. The manufacturer must adhere to the quality control plan and the customer indicates which of the checks he wishes to witness.

36. The customer approves the quality control plan for manufacture of MOX fuel pellets, MOX fuel rods and MOX fuel assemblies in MDF before the production campaign begins and only those modifications approved by the customer can be incorporated once the quality control plan has been approved.

37. Customers carry out their own checks on BNFL's adherence to the QC plans as the fuel is manufactured.

3. <u>INVESTIGATION FINDINGS</u>

38. Discussions with BNFL management and interviews with MDF staff clearly demonstrated that several process workers had not been following quality control procedures for the quality assurance checks on the diameter of a sample of each 'Lot' of pellets produced in the manufacturing process. Instead of carrying out the required diameter measurements and recording them on a spreadsheet for the customer (to confirm that the fuel pellets were within the tolerances specified by the customer), some process workers simply used previous spreadsheets, manipulated the data and recorded it as if they were measurements of the designated Lot. These false spreadsheets were then authorised by Quality Controllers who might have been the same individuals as those who make the measurements.

39. There is no doubt that data falsification took place and MOX fuel assemblies have been produced and in some cases delivered to the customer with Quality Assurance documentation which included falsified data.

Extent of Falsification

40. The extent of the data falsification was initially determined through the EMSU statistical analysis. The results of this analysis were then discussed and compared with BNFL's own statistical analysis to give the complete story.

41. The EMSU analysis found that:

    1. the 22 Lots identified by BNFL as falsified had indeed been falsified by the type (a) method as described in Section 1.4 above;
    2. in addition to these 22 Lots, there was firm evidence that a further two Lots contained false data of type (a);
    3. there were an additional two Lots which had high numbers of duplications within a spreadsheet, type (b), one of them being one of the Lots originally declared by BNFL as unusual and later discounted by BNFL; and
    4. the internal tests devised to find type (c) faults confirmed the two Lots under type (b), but did not identify any further falsified Lots.

42. A manual check by NII of line repeats across BNFL's original list of 10 unusual datasets also identified an additional four Lots as containing 'suspect' data.

43. The HSE statistical analysis was shared with BNFL, which passed it on to its customer Kansai. The results were also explained in some detail to the Japanese Nuclear Regulators in the Ministry of International Trade and Industry, MITI. BNFL carried out further statistical analysis of the data and informed NII that a further Lot (P814) contained falsified fuel pellet diameter data. NII checked the method of falsification to see why its own statistical analysis had not identified this Lot. The reason was that the protocol adopted for HSE's analysis would not have identified this method of falsification which was to copy a large section of one spreadsheet to a different location in the other. The existence of Lot P814 does not invalidate the analysis or conclusions of HSE's statistical work. Table 1 lists all the Lot numbers that have been found to contain falsified data. This shows that there are 31 Lots known to be affected. Pellets from these Lots have been used to produce a number of fuel assemblies, some of which remain at Sellafield. Eight assemblies have been

delivered to Kansai, of which four assemblies contain pellets from Lots known to have been affected.

Who was Involved

44. The NII investigation into who was involved in data falsification centred mainly on the statistical analysis report. It was possible from the data to identify when each AQL sample was 'measured' and hence from the staffing records identify which of the five shifts working in MDF were involved. This analysis showed that four of the five shifts were involved to varying extents with the data concerned.

45. Initially BNFL only identified one shift responsible for the falsification. Three process workers from this shift, one of whom admitted falsifying records, were subsequently dismissed. NII has had discussions with BNFL on the more widespread involvement of MDF staff. BNFL has confirmed that some members of staff have been told that they face potential disciplinary action.

46. The above shows that not only were some of the process workers who were given the tasks of measuring the pellet diameters and recording them on the computer spreadsheet involved, but also some of the process workers who carried the Quality Control Stamps were either party to the falsification or were not checking that measurements were being taken. The conclusion is that a number of these individuals were also negligent and not carrying out their duties properly. There are also implications for some members of Shift Management. Either they were not doing their jobs properly by failing to supervise adequately and control activities on their shifts, or they were party to the falsification of records.

47. NII interviewed MDF's management, shift team managers, shift team leaders and process workers in the area of MDF where the AQL measurements take place. None of the management or supervisors admitted to any prior knowledge of falsification. Of the process workers interviewed, only one admitted to falsifying data. NII also interviewed QA and QC staff including the person who originally identified falsification of data. Up to that point none of the people interviewed admitted being aware that falsification was happening.

Why Falsification Happened

48. There can be no excuse for anyone falsifying records, particularly on a nuclear licensed site. NII's investigation therefore was not looking for mitigating circumstances: rather it was trying to establish factors which may have contributed to the environment which led people to falsify records rather than follow procedures. NII was also keen to see if there were circumstances which had lessons for other parts of the Sellafield Site. The Site Inspector and NII experts in quality assurance and human factors interviewed BNFL staff in MDF.

49. The NII investigation revealed inadequacies in the working environment and in BNFL's systems and procedures, which may have led some process workers and QC inspectors to look for ways of bypassing the fuel pellet diameter secondary measurement tasks. These are discussed below.

Control and Supervision

50. The control and supervision of operations in MDF was one of the key areas where NII found the BNFL arrangements to be inadequate. Managers did not spend enough time talking to and observing workers, particularly in the fuel rod fabrication area. Shift Team Managers (STMs) tended to spend more of their time in the area of the plant where the MOX fuel pellets were being produced, because of 'bottle neck' problems, rather than in the fuel rod fabrication area where the secondary measurements of pellet diameter took place.

51. From interviews, NII learned that little supervision of this task took place other than to simply do ad hoc checks on progress. One Shift Team Leader (STL) said he had little involvement with the pellet diameter inspection, even when covering for the STM, other than to look at the speadsheet to check that the number of out-of-specification readings was acceptable. The general view amongst managers was that the secondary check on pellet diameters was considered to be a low risk job not requiring supervision. NII also found that the STL's knowledge of the 'QC Overinspection Instruction' was limited. Two of the three STLs interviewed had never read it and one STL had not seen it until the day of the interview. This showed deficiencies in the training of key staff within MDF and raised concern about the overall safety culture on the plant.

52. It was clear that the level of control and supervision of fuel pellet diameter inspection had been virtually non existent. This may have sent out entirely the wrong message to the process workers and QC inspectors regarding the importance of the task, and acted as a demotivator.

Training and Awareness

53. It was clear to NII that for some process workers and QC inspectors the awareness training for the fuel pellet overinspection measurement task was ineffective. NII also found non-compliance with BNFL's own procedures for authorising persons to carry out the overinspection task. It was also obvious to NII that some of the procedures were themselves deficient.

54. Five out of the six STMs and STLs interviewed believed that those process workers who carry out overinspection tasks were aware that it is used to confirm the validity of the automatic 100% measurements (avoiding problems at the rod load stage) and gives confidence in the quality of the product to the customer. However, when NII questioned the training provided to staff undertaking inspection of fuel pellet diameter, no reference was made to awareness of the importance of the task.

55. Without effective awareness training or briefing to the process workers carrying out these fuel pellet diameter measurement tasks, such individuals are unlikely to appreciate the importance of the task or take ownership of it. This was another example of management failure within MDF.

Workload and Deadlines

56. It had been suggested that one of the reasons for falsifying the data, eg copying previously measured diameter data rather then measuring the 200 pellet sample in each Lot, was because of high workload. NII inspectors discussed workload with the STMs and STLs. All those interviewed reported a gradual increase in throughput taking place, but all believed that the higher throughput was within the capacity of the plant and the workforce, and did not put an uncomfortable workload on staff.

None of the STMs or STLs believed that falsification of quality checks was a result of excessive workload.

57. NII examined the list of operations surrounding the 200 fuel pellet sample measurements with their duration times. Whilst there was little margin between shift length (3 x 8 hours) ie three people on the shift allocated to these duties, and the summated man hours for the various tasks (23.8 hours), NII could find no evidence to prove workload was a significant factor in falsification.

Tedious Nature of the Task

58. The system adopted in MDF for carrying out the overinspection task of the 200 fuel pellet diameter sample was tedious and could have been made easier for the process workers involved. A system where one operator places a pellet in a laser micrometer, calls out the diameter reading and another operator enters this manually into a computer spreadsheet is clearly far from ideal. Automation of the laser readout straight to the computer would have eliminated one tedious task, reduced the likelihood of errors and allowed the sharing of the remaining task of placing the pellets in the micrometer for measurement. The failure to recognise and redesign this during the years of operation is another example of BNFL's failure to manage MDF properly.

Ergonomics

59. NII examined the ergonomics aspects of the task and found the following:

    1. The overinspection task, although not overly demanding in a purely physical sense, was sufficiently badly designed to make almost all of the task steps more than a minor nuisance to anyone who has to perform them on a repetitive basis for any extended period of time.
    2. The amount of eye-to-hand co-ordination, precision, general dexterity and patience that is required on the part of the operators, over what is potentially a long period of sustained concentration for the operator, is non-trivial and is likely to be regarded as being more than a minor nuisance after the first few initial task cycles.
    3. Other than the prospect of an eventual QC stamp which is, in effect, an internally generated record, and ultimate payment for completing the shift, there is no obvious recognition for diligent performance.
    4. Other workstations within the plant have also been poorly designed
    5.

60. In the light of these findings and with the benefit of hindsight, NII concluded that the occurrence of non-compliant behaviour is not at all surprising. This should have been recognised by BNFL during the design and commissioning of the plant and steps taken to improve the ergonomic design to reduce the deleterious impact on the process workers.

Computer Security

61. During NII inspection of the overinspection process, BNFL staff demonstrated how a spreadsheet or part thereof could be copied and how randomly 'invented' data could be easily input or copied. Because of human frailty, the ease with which falsified data could be entered into the computer was clearly a contributory factor to this event.

Quality Control

62. The procedures for QC inspection of fuel pellets were inspected. NII found that:

- The Quality Control Plans (QCPs) for the manufacture of fuel pellets and MOX fuel rods were developed to meet customer requirements and were approved by the customer;
- The first discovery of potentially falsified data was made by a member of the MDF QC team and reported to management, who then started their own investigation;
- Lloyds Register Quality Assurance had not withdrawn or suspended its quality certification of the plant on the basis that 'there was no evidence of a failure of the 'Quality Management System'; and
- There was no sign that any of the other key records or data used to measure and confirm the quality of the final product ie the MOX fuel assembly had been falsified. 63. NII is satisfied that the overall approach to quality control and quality assurance is appropriate, but the procedures and supervision for the AQL pellet diameter measurement need improvement as detailed above. The issue of allowing process workers to check their own work, without adequate management control and supervision, needs to be reassessed.

Adequacy of BNFL's Own Investigation

64. NII has closely monitored BNFL's own investigation to satisfy itself that BNFL has adequately investigated the falsification issue and to check compliance with the requirements placed upon a nuclear site licensee to ensure all events are properly investigated and lessons are learned. From the outset, BNFL has clearly expended considerable effort to establish the extent of the problem and why it occurred. Since 10 September 1999, when BNFL first informed NII of the situation at MDF, there has been considerable dialogue with the Company in order to monitor and track developments.

65. Like HSE, BNFL developed a computerised checking method to determine the number of matches between pellet Lots. Initially BNFL focused on matching values for the 600 data points in Lots within a given Batch: this was then extended to cover matches between all the pellet Lots, which for some 400 Lots involved some 80,000 dataset comparisons. The BNFL methodology initially only investigated two other ways of copying/fabricating data in addition to the above matching process. These were the direct copying of a single line of three data entries to other lines in the same spreadsheet, and the random copying into other spreadsheets. More recently, BNFL has looked at repeat entries between columns of spreadsheets. This analysis method identified an additional Lot (P814) containing falsified data.

66. Although BNFL has done a thorough investigation into direct copying of information within and between spreadsheets, it recognised that the analysis could not be exhaustive. However, it is unlikely that even a much more sophisticated investigation into methods of falsification would identify, with complete confidence, every spreadsheet containing falsified data.

67. BNFL's management investigation was set up to determine, inter alia, the circumstances surrounding the event, the root causes and to make recommendations to prevent recurrence. The BNFL investigation made the following recommendations.

1. Automation of the transfer of measurements from the laser micrometer to QC datasheets and consideration of automation of other aspects of fuel pellet diameter overinspections.
2. Raise awareness of the expectations of standards in the nuclear industry.
3. Review the workload of STMs to ensure they have adequate time for supervision of all operations under their control.
4. Review of accountability for Quality Control between QC inspectors and the STM.
5. Re-accreditation of QC stamp holders including a review and re-education of the understanding and application of QA systems and QC standards.
6. Improve computer security to eliminate the potential for copying of QC data between spreadsheets.

<u>Implement a hierarchical reporting system for product QC issues</u>

NII studied the investigation report and whilst it supports much of what is recommended as being sensible, prudent and achievable, it identified a fundamental limitation in scope, ie the assumption in BNFL's initial investigation that the problem was caused by three individuals on one shift. BNFL had in parallel initiated other investigations to establish the extent of the problem in terms of the Lot numbers and shifts involved. As shown above, the NII analysis identified four out of the five shifts as being involved to varying extents.

68. Further, the initial BNFL Management Investigation seemed to attribute the main cause to shortcomings amongst some process workers and QC inspectors, rather than look at the broader management responsibilities which allowed the falsification to happen. However, worthy of specific note was the recognition that training, use of instructions and supervisory control had not been adequate. The BNFL team also recognised that there was a need to produce a fundamental change in QC inspection functions with the appointment of accountable persons to oversee QC inspections and check QC related data on each shift.

69. Overall, NII concluded that BNFL has carried out a thorough investigation into the circumstances surrounding MOX fuel pellet diameter data falsification. BNFL's initial investigation was too hurried and limited in scope but this has since improved: generally the investigation has been well conducted and has identified the key areas for preventing further falsification.

Management Shortcomings in Control and Supervision

70. NII has interviewed a number of operational and QA staff in MDF. It was obvious that there had been little supervision of the pellet diameter overinspection. The demarcation of effort between shift team leaders and managers was generally that the manager oversaw operations in the fuel pellet production area (the bottleneck), and the leader those in the fuel rod assembly area. NII has some concerns that there may be a conflict of loyalties for shift team leaders. The conflict arises from STLs being members of management yet not wishing to be alienated from the process workers. NII found no evidence of this in MDF.

71. The shift team managers had insufficient time to both manage staff and keep the plant operating. As a result, effort was given to resolving plant problems, and jobs which were seen as a lesser priority were allowed to slip. One of these was supervision of the AQL measurements. BNFL has recognised the overload by

removing the task of preparing 'permits to work' from shift managers and appointing an additional process engineer.

72. Management presence on MDF was clearly insufficient in terms of both time on plant and in having a questioning attitude to what was happening. For example during one inspection, conditions were seen by NII which should not be allowed in a plant manufacturing nuclear fuel. Once pointed out to the management, matters were quickly remedied. The issue of time on plant remains. NII concludes that there is insufficient management resource to ensure effective management of MDF.

73. The problems of MDF are not all recent: some, such as the poor ergonomics of the workstation, have existed since the plant was built. The implication of this is that managers of one of Sellafield's key businesses did not have the necessary time to devote to supervision of front line production activities. These events demand careful consideration at the most senior levels within BNFL.

4. ASSESSMENT OF THE SAFETY OF MDF FUEL IN USE

74. When NII was first informed of the falsification of fuel pellet diameter data, one of the major concerns was to gain an understanding of the potential impact upon the safety of fuel that was either operating in reactors or, as was the case in Japan, about to be loaded into the reactor. NII asked BNFL to provide a justification for why it believed fuel safety would not be prejudiced, and NII fuel specialists assessed the response. In this section of the report the key fuel rod characteristics which can affect the safe performance and reliability of the fuel assembly in the reactor are discussed, along with NII views on the measures taken in MDF to ensure that the key parameters which affect these characteristics are within the required fuel assembly specification.

75. BNFL commenced production of LWR MOX fuel via the Short Binderless Route (SBR) in 1990 and since then it has been engaged in a MOX fuel development programme to demonstrate the safety of SBR-MOX fuel under normal and abnormal reactor conditions. This programme has included:

    1. characterisation and physical property measurements on unirradiated pellets;
    2. in-pile testing in both test and commercial reactors;
    3. post irradiation examination of commercially irradiated fuel; and
    4. the development of fuel performance modelling capability through the use of computer codes.

Factors Affecting Fuel Safety in Use

76. Most manufacturing defects in fuel will not precipitate a nuclear accident. These require a significant power-coolant mismatch and occur as a result of a loss of cooling due to a variety of causes, or from a loss of control of neutron power causing the fuel rods to overheat. Manufacturing defects or irregularities, if outside specific tolerances can cause the fuel rod cladding to fail giving rise to the release of fission products into the reactor coolant circuit. This does not cause an immediate threat to the public or the power plant workers but it will increase the contamination levels in the reactor and make maintenance activities more difficult. Most nuclear reactor designs anticipate some level of fuel failure and have coolant cleanup systems to remove fission products. However, to avoid unnecessary circuit contamination, nuclear plant operators require their fuel to have high levels of reliability.

77. There are a number of fuel pellet and fuel rod characteristics which can influence reliability and hence safety and operability performance in the reactor. Tables 2 and 3 list the quality characteristics (for fuel pellet and fuel rod respectively) which the fuel manufacturer has to address. Fuel rod failure mechanisms and how they can be influenced by fuel pellet and rod quality characteristics are detailed in Appendix 3.

78. Fuel rods are designed to produce the required power output within conservative specifications which are aimed to produce very low manufacturing defects (which can result in clad failure as discussed above), and be tolerant both to normal operation and to a range of fault conditions. The designers, in specifying the fuel requirements, make allowances for the effects of irradiation during normal operation. Therefore, the most important characteristics which can have an influence on fuel rod integrity during operation in the reactor are:

Fuel pellet cracking	Fuel densification	Fuel pellet swelling	Fission gas release from the fuel matrix	Fission product migration
Clad creepdown	Fuel rod growth	Clad corrosion and crud deposition	Thermal conductivity (of the fuel/clad gap and the fuel itself)	

79. In relation to the MDF fuel, the fuel rod cladding and other assembly components are supplied by the customer so for the purpose of looking into the likely implications of fuel pellet diameter overinspection falsification, NII concentrated on the role and significance of the fuel pellet characteristics.

80. The key characteristics are those associated with the physical properties of the fuel pellet, ie pellet density, fuel grain size, porosity, and homogeneity of the uranium and plutonium oxides, the surface condition including chips and cracks, the shape of the pellet and the pellet dimensions.

Fuel Pellet Physical Properties

81. A number of quality checks are made of the physical properties of the pellet. Geometric density must be within a specification range to a 95/95 confidence level; this is calculated for a random sample of 20 pellets per Lot by measuring diameter, length and weight. Resinter behaviour is tested to demonstrate that the material is thermally stable; 10 pellet samples taken at regular intervals must meet the specification on geometric density following high temperature extended sintering. PuO_2 particle size and grain size are measured using colour alpha autoradiography of ceramography samples; two pellet samples are taken at regular intervals. Sellafield Analytical Services measure a number of chemical characteristics, in particular the plutonium enrichment. At a later stage in the process, when the pellets have been inserted in fuel pins, the enrichment of each pellet is checked using a special detection system which records any unusual enrichments.

Fuel Pellet Surface Condition

82. Every pellet is visually inspected for chips, cracks, surface defects and major shape abnormalities. Surface roughness must be within the specified limit, and random samples of five pellets are taken at regular intervals. The surface condition of the pellets is important because pellet chips can cause clad stress intensification, and a fuel crack can cause clad wall-thinning during operation.

Fuel Pellet Dimensions

83. As shown in Tables 2 and 3, there are several dimensional checks which are important to fuel quality. Accurate measurement and confidence in the pellet's diameter is important because if the pellet is too large it will not fit into the cladding tube. If it is too small it may move around and possibly cause clad collapse: cracking of the clad gives rise to fission product release. BNFL recognises the importance of this and provides several quality checks on the process. The key questions are how much reliance can be placed on the 100% automatic measurement of pellet diameter and the failsafe system for rejecting pellets which are out of specification; what additional value does the 200 pellet manual AQL check give; what value can be gained from the diameter measurements taken for density measurements, and what support in relation to diameter measurement can be derived from the 'throat bush' test for oversized pellets and the 100% fuel rod radiographs for undersized pellets.

84. There is a robust case for saying that the 100% primary diameter check alone will provide adequate confidence that all pellets are within specification. In order to obtain some indication of the sensitivity of fuel performance to pellet diameter, NII asked BNFL to provide a safety assessment. BNFL used the ENIGMA code which had been jointly developed with British Energy. This was backed up using the Westinghouse PWR design and licensing code, PAD. The range of pellet diameter examined was nominal ± 0.2 mm (this compares with the MOX fuel pellet specification range of nominal ± 0.0125 mm. The key performance parameters examined were:

1. peak in-life fuel centre line temperature;
2. end of life fission gas release;
3. end of life rod internal pressure;
4. peak in-life clad hoop strain;
5. peak in-life clad concentrated hoop stress.

85. The results showed that only beyond the range of ± 0.1 mm of nominal, ie 8 x the specification range, could the effects become major. BNFL claims that in the event of the 100% diameter check not working as intended, the throat bush used as part of the rod filling process would prevent oversized pellets being loaded. The company equally claims that undersized pellets of 0.1 mm less than nominal would be detected by the fuel rod radiographs. The overall conclusion by BNFL was that the accuracy of the 100% automatic check, plus the relatively low sensitivity of the relationship between fuel pellet diameter and fuel rod failure, was such that the absence of the AQL check would not impact on the ability of the fuel to perform safely in reactor operation. 86. The total length of fuel in a fuel rod is important because it determines the length of the fission gas plenum and hence has an effect on internal rod pressure, which if incorrect could result in fuel rod failure as explained in Appendix 3.

86. This is measured in the following way: approximately 730mm sub-stacks of pellets are length checked and weighed prior to being manually loaded into the neck of the fuel rod. After loading the pellets, the free space in the rod is checked with a bar with two notches defining the acceptable limits. This check is for process control only and is not part of the certification.

87. For certification the correct length of the fuel stack is checked by measurement of the plenum length and the overall length of the fuel rod. The plenum length is measured from the radiograph of the fuel rod. The radiograph is also examined to check the absence of gaps. For the current order, the customer checks every weld radiograph and a random selection of the full-length radiographs.

88. The fuel manufactured in MDF for commercial purposes is covered by customer approved Quality Control Plans. These define for each characteristic the requirements of the specification, the method of analysis or measurement, the frequency of measurement and/or sampling, and how the information is recorded There are a number of characteristics/parameters whose quality is controlled and assured. For the pellets, these include physical and chemical properties, surface condition, dimensions and shape. X-radiography of the rods is carried out to check that there are no gaps or unintended materials in the fuel column.

NII Views

89. NII is satisfied that the fuel manufactured in MDF will be safe in use in spite of incomplete QA records caused by the falsification of some AQL data by process workers in the facility. The NII takes this view on the basis of the robustness of the fuel manufacturing process and the totality of the checks made on the key parameters.

90. Firstly in relation to the physical properties of the SBR-MOX fuel pellets, the MOX demonstration programme coupled with BNFL's extensive expertise in oxide fuel manufacture and NII's examination of the plant and processes carried out in the MDF fuel pellet production area are such that NII is confident that the MOX fuel pellets produced in MDF are of the required quality and will perform as designed in the reactor.

91. Second in relation to surface condition, NII is satisfied that the rod radiography check (which is examined by both BNFL and the Japanese customer) will detect crack, chips or other defects which are outside the customer's specification.

92. Finally NII is satisfied that the 100% automatic check on fuel pellet diameter is sufficiently robust to ensure that only fuel pellets which will not prejudice the safety of fuel pins in operation are used in fuel rod assembly. Comfort is also taken from the throat bush which limits the upper diameter and the radiograph checks to detect undersized fuel pellets. The combination of pellet density, stack length and stack weight provide further reassurance as to mean pellet diameter.

5. REQUIREMENTS FOR THE RESTART OF MDF

93. The NII investigation has revealed significant shortcomings in the suitability of the plant, safety culture and management, especially the control and supervision of operations. The plant is currently shut down and NII will only consent to its restart when significant improvements have been made. The required improvements are discussed below.

Plant and Equipment

94. As described above MDF is a demonstration facility: it is not a purpose built production facility like the Sellafield MOX plant. Consequently the ergonomics of the plant leave a good deal to be desired. NII recognises that there are only limited improvements that can be made. However, it is essential that the ergonomics of the pellet diameter measuring station should be improved. NII fully supports BNFL's own recommendation to automate this process so that the readings from the laser micrometer are fed directly into the computer spreadsheet without the need for manual intervention.

Recommendation 1:

BNFL should automate the recording of the AQL sample fuel pellet diameter measurements.

95. The measurement of fuel pellet diameter to meet customer's Quality Assurance needs is a necessary but tedious manual task. Consideration should be given to improving the plant measuring station to reduce the amount of operator involvement.

Recommendation 2:

BNFL should give consideration to improving the measuring work station to reduce the need for operator involvement in the selecting and positioning of fuel pellets in the laser micrometer.

96. The ease with which the computer data logging system could be manipulated was certainly a factor in the fabrication of the QA records. Improvements in this system should be made to prevent interference with data, especially the ability to copy data both within, and from one spreadsheet to another.

Recommendation 3:

BNFL should improve the computer security of the QA data logging system in particular to prevent copying both within and from one spreadsheet to another.

Process Workers

97. HSE's statistical analysis has shown that four out of the five shifts are implicated in the falsification of pellet diameter data. This means that some people actively bypassed the required procedures for measuring and recording AQL data. Others almost certainly knew what was going on but did not report it. This shows that there is a serious safety culture problem and a lack of awareness and/or care about why specific tasks are done in the production of MOX fuel. This attitude is unacceptable on a nuclear installation, especially one which is producing the fuel for use in nuclear

reactors. NII will not allow restart of this plant until significant changes have been made in the staffing of the plant.

Recommendation 4:

BNFL should make every effort to identify all those people who deliberately falsified records and take appropriate disciplinary action. Any persons found to have been involved in deliberate falsification of records should not be allowed to work in MDF or in any other safety related plant on the Sellafield site until such time as they have been retrained and demonstrate they are competent to undertake safety related work.

Recommendation 5:

BNFL should make every effort to identify all those people who knew about the practice of falsifying records but did not take action. These people should be removed from MDF and retrained.

Recommendation 6:

BNFL should ensure that all other staff in MDF are retrained to improve their awareness of the importance of the operations in MDF, why they need to be done and why process workers must follow procedures.

98. The practice of allowing process workers to hold QC stamps which in effect allow them to check their own work is another contributory factor to this event. The question needs to be asked whether such practices are appropriate for the manufacture of nuclear fuel. BNFL should re-examine this practice. NII will expect to see clear accountabilities for QC inspectors who must be trained and dedicated to the task. A QC inspector must have the independence and strength to resist any potential pressures from both the process workers and management to ensure that tasks are completed properly.

Recommendation 7:

BNFL should review the role of QC inspectors in MDF to ensure they have the independence and accountability to give confidence that work is being completed properly.

Supervisors

99. Clearly front line supervision failed on this plant. The Shift Team Leaders and Shift Team Managers concerned did not adequately perform their jobs either in supervising or controlling these key activities. The roles of these supervisors need to be re-examined. In particular, BNFL needs to establish to what extent they knew about what was going on - if they did then BNFL should take appropriate action. NII will not allow the restart of MDF with any supervisors who condoned falsification of records.

Recommendation 8:

BNFL should re-examine the role of Shift Team Leaders to ensure that management functions are clearly identified and justified.

Recommendation 9:

BNFL should make every effort to identify any supervisors who knew about and condoned falsification of records. Such people should be appropriately disciplined.

Recommendation 10:

BNFL should ensure that all other STLs and STMs are retrained to ensure they are aware of the importance of their jobs and the need to ensure staff who report to them follow procedures.

Plant Management

100. The NII investigation has shown that the plant management allowed a situation to develop where some people thought it was acceptable to falsify records rather than to follow procedures. The management should take responsibility for staffing the plant with some people who did not have the right skills or attitude required for the production of nuclear fuel. Also the managers should take responsibility for allowing poor ergonomic practices and not initiating plant improvements to ease process worker tasks. It was also evident from the NII investigation that plant managers did not spend sufficient time on the plant, observing what was going on and talking to staff. If they had, they would have realised that improvements could have been made. Their absence of 'walking the plant' also had a negative effect on staff morale and general attitude to the importance of the task the staff were engaged on. NII will not allow restart of MDF with the current management arrangements or practices.

Recommendation 11:

BNFL should review the roles of previous plant management to determine the extent to which they contributed to the degradation in working practices in the plant.

Recommendation 12:

BNFL should review the suitability of the current plant management to run MDF.

Recommendation 13:

BNFL should ensure that any future management team members are aware of their responsibility to ensure the plant is operated to standards required of a nuclear establishment and that they are given sufficient time to spend on the shop floor talking to their staff.

Site Management

101. At the same time as BNFL first notified NII of falsification, NII was conducting a team inspection into control and supervision at Sellafield. Many of the findings of this investigation are reflected across the site in the findings of the team inspection. NII has written to BNFL specifying under its licence that it refers to its Nuclear Safety Committee a report or reports on:

- the findings of BNFL's investigation into the possibility of data falsification at the Sellafield site
- the additional countermeasures implemented at the Sellafield site to prevent data falsification
- the implementation across the Sellafield site of improvements arising from the investigation into data falsification at the B33 MOX Demonstration Facility.

NII requires the site management to urgently consider the implications of this event for other parts of the site.

Recommendation 14:

BNFL should urgently consider the implications of the MDF event for the Sellafield site and provide to NII a report or reports on its proposed remedial actions.

BNFL Corporate Management

102. For an event of this significance to have occurred, there has clearly been a lapse in the communication chain between the plant and BNFL's corporate management. Such lapses should not be allowed to occur. It is obvious that higher levels of management were unaware of day to day practices, which when exposed by this event, were considered unacceptable.

Recommendation 15:

BNFL should investigate why its senior management had allowed the situation in MDF to develop and to provide a report to NII on how it intends to prevent a recurrence.

6. <u>CONCLUSIONS</u>

APPENDIX 1

Summary of events

On 20 August 1999 a member of the Quality Control Team in B33 MOX Demonstration Facility (MDF) identified a similarity between mean pellet fuel diameter measurements reported on the QC release certificates for the secondary sample checks of two successive Lots. These were discussed by the QC Team in MDF on 23 August. Plant management was informed of these similarities on 25 August and the Shift Team Leaders were asked to pay particular attention to inspection of pellets pending completion of QC release.

On 31 August BNFL's analysis of data for several Lots showed many of the mean pellet diameter values in successive Lots to be the same, and the MDF QC management initiated a computerised analysis of the data. Discussion with individuals concerned began on 1 September 1999. On 6 September the MOX Senior Team was informed that some falsification of data may have occurred.

On 3 September a process worker in MDF admitted deliberate falsification, and a second process worker said that he was aware falsification was taking place.

On 9 September the QC management updated the MDF Operations management on the results of the preliminary investigation. Over 9/10 September Trade Union officials met plant management with individuals concerned to try to understand the extent of the problem.

On 10 September the Independent Newspaper indicated to BNFL its intention to publish an article in the newspaper concerning the fact that BNFL inspectors had falsified QC data on MOX pellet diameter. The article was eventually published on 14 September.

On 10 September Mitsubishi Heavy Industries (the fuel vendor to Kansai) and NII were informed of the situation. NII maintained contact with BNFL thereafter throughout the weekend until the beginning of its on-site investigation. BNFL reported to NII that on 12 September 1999 it had found 11 Lots with falsified data and 9 "unusual" Lots.

12 September: NII obtained BNFL's agreement not to restart production until NII had been notified.

NII was told that on 14 September the BNFL QC Team reported a further five sets of falsified data, and one further set of falsified data a day later. On 14 September NII began its on-site investigation into the incident.

14-16 September: Visit to the MDF plant by NII Site Inspector and NII Management to begin on-site investigation into the event. This included some interviews.

On 16 September BNFL reported four further sets of falsified data and one additional unusual dataset giving a total of 22 falsified datasets and 10 unusual datasets. On 16 September MDF Operations Manager reported that BNFL believed that falsification of data had been undertaken principally by one of the five shift teams.

20-21 September: Visit to plant by NII Site Inspector and NII Senior Management. This included a plant inspection and meeting with officials from the Ministry of International

Trade and Industry (MITI), Japan. NII told MITI that it would be carrying out a thorough independent analysis of the pellet diameter data for Kansai.

21 September: NII wrote to the Japanese Embassy in London in response to a letter the previous day from the Economic Counsellor. The letter explained that it would "take some time, possibly several weeks, to check all of the data relating to the fuel which [was] currently en route to Japan". The letter also said that NII understood that BNFL had "already told the Japanese team visiting Sellafield that one Lot of MOX fuel pellets whose secondary sample checks on diameter show "unusual" results has been used in the manufacture of two fuel assemblies [then] currently en route to Fukui".

On 22 September at a meeting at NII's offices in Bootle, BNFL reported that its continuing investigation had concluded that there were 22 falsified data Lots and one unusual data Lot. The other nine 'unusual Lots' were eliminated by BNFL. All pellet Lots for which falsified datasets had been reported had been used to produce fuel rods and assemblies for Takahama 3, and were still at Sellafield. The pellets for an unusual Lot had been used to produce fuel rods in two of the eight fuel assemblies for Takahama 4, which at that time were in the process of being transported to Japan.

22 September: HSE's independent statistical analysis of the pellet diameter data for Kansai was initiated.

28-29 September: Visit to plant by NII Site Inspector to conduct interviews with the Shift Team Leaders (STLs), Shift Team Managers (STMs) and the Head of MDF Operations.

8 October: Visit to plant by NII Quality Assurance (QA) Specialist to investigate QA aspects of the event.

12-13 October: Visit to plant by NII Site Inspector and Human Factors Specialist to discuss ergonomic aspects of the event.

25-26 October: Visit to plant by NII Site Inspector to witness three separate sets of dual 5% secondary diameter checks.

29 October: The statistical analysis by HSE's EMSU of the data was completed.

3 November: An update provided by BNFL reported 22 falsified data Lots, one Lot having some similarities with a previous Lot, one Lot having greater than normal number of pellets with three identical diameters (ie cylindrical), and one Lot having a greater than normal number of identical pellets.

8 November: BNFL was informed that it would have to produce a safety case and seek NII's agreement before it could restart MDF. NII wrote again to the Japanese Embassy confirming that "two of the assemblies containing pellets with suspect data are in Japan." A copy of this letter was placed in the House of Commons Library.

10 November: Visit to plant by NII Site Inspector and an Inspector from the Radioactive Materials Transport Division of the Department of Environment, Transport and Regions (DETR) to discuss BNFL countermeasures to prevent recurrence of the event.

11 November: A meeting took place between HSE and BNFL to discuss work necessary before MDF is permitted to restart.

17 November: A meeting took place between HSE (NII and EMSU) and BNFL to discuss the findings of HSE's statistical analysis of the secondary pellet diameter data. On the same day NII and BNFL met to discuss BNFL's proposals for a safety case for the restart of operation in MDF.

23 November: Visit to plant by NII Site Inspector to investigate ergonomics aspects of the event.

8-10 December: Visit to plant by NII Site Inspector and Human Factors specialist to undertake a restart readiness inspection.

13 and 14 December: Meeting between NII and MITI officials to explain the results of HSE's statistical analysis. NII confirmed the facts set out in earlier letters to the Japanese Embassy i.e. that two of the assemblies (MKP 005 and 006) in Japan contain pellets believed to have suspect data. HSE staff went to some lengths to explain that although the 8 November letter had used the word "suspect" in relation to these assemblies, HSE considered that there was a vanishingly small probability of these results [for Lots P783 and P824] having occurred by chance.

15 December: That evening BNFL reported to NII that following further investigation, data for a further Lot, P814, had been found to be copied from a previous lot.

16 December: Following the discovery by BNFL of the additional falsified Lot, P814, NII asked for a further meeting with MITI which was held the same day. NII confirmed to MITI that P814 had been falsified, and that this now meant that two further assemblies in Japan were considered to be affected. Taken together with those assemblies identified previously, this now meant that a total of four assemblies (MKP 005, 006, 007, and 008) out of the eight assemblies currently in Japan contained pellets whose secondary diameter data was considered to have been falsified.

19 December: Visit to MDF by the Chief Inspector for a plant inspection.

20 December: BNFL Senior Management met with NII Senior Management at Bootle to discuss the improvements which NII require to be implemented before permission to restart would be granted.

21 December: NII wrote to BNFL listing a number of areas for BNFL to address to NII's satisfaction before agreement to restart would be granted.

22 December: NII wrote to BNFL specifying under the nuclear site licence, that BNFL should demonstrate to its Nuclear Safety Committee how it has satisfied itself that the lessons learned from the MDF event will be disseminated to the rest of the site.

11 January 2000: NII met with BNFL to discuss the process which had been used to identify Lot P814 as containing falsified fuel pellet diameter data.

APPENDIX 2

Important fuel quality characteristics

The following sections give details of the most important fuel quality characteristics, how BNFL measures them and assures the customer that the required standards are met. (NB Details of the pellet diameter specification are given elsewhere in the report. Some of the others have already been mentioned in the descriptions of the MOX fuel production process, Section 2.2, and the factors affecting fuel safety in use, Section 4.1 of this report).

Chemical Composition

Pu/U isotopes, Pu enrichment, Metal content ratio, Oxygen/Metal ratio, impurities, gas content and pellet solubility.

Measurements are carried out by Sellafield Analytical Services and Springfields Chemical and Metallurgical Services (NAMAS accredited). The measurements are manually entered onto a computer.

Visual Inspection

Visual inspection of the pellets identifies chips, cracks, surface defects, major shape abnormalities.

Every pellet is visually inspected by operators - QC Inspectors randomly sample up to three pellet trays per lot (~300 pellets/tray). If one defective pellet is found in these inspections the lot is rejected. Results are manually recorded on Lot record sheet.

Additional visual inspection of pellets, chosen at random is performed by the customer.

Pellet Length

Random sample of 20 pellets per lot - length measured using a micrometer with precision 1 µm. Length must be within specified range with 95/95 confidence level.

Results are computer logged and manually recorded on Lot record sheet.

Geometric Density

Random sample of 20 pellets per lot - outer diameter and length are measured using micrometer (see above) and weight is measured using electronic balance - density calculation is computerised and results are stored on computer.

Geometric density must be within specification range a 95/95 confidence level.

Resinter Behaviour

This test is to demonstrate that material is thermally stable. Ten pellets samples are taken at regular intervals agreed with the customer. All pellets must meet specification limit on geometric density following high temperature, extended sintering. Data is computer logged and manually recorded on resinter record sheet.

End Squareness

Random sampling of 20 pellets is taken at any point in production for sampling after press tooling changes, when end features may alter. End squareness is measured using a gauge with a precision of 1 µm. Measurement must be less than specified limit. Results are computer logged and manually recorded on Lot record sheet.

Dish and chamfer

A random sampling of six pellets (12 faces)/Lot are taken at the same time for chamfer height and chamfer length measurement using image processing with precision 0.01 mm, dish depth is measured using depth gauge with a precision of 1 µm. Each feature must be within the specified limits. Results are computer logged and manually recorded.

Surface roughness

A random sample of five pellets is taken at regular intervals, measured using a proprietary gauge with precision 0.02 µm. Roughness must be within the specified limit. Results are computer logged and manually recorded on Lot record sheet.

Pu spots - Pu homogeneity

PuO2 particle size is measured using colour alpha autoradiography of ceramography samples - the measurements are made on two pellets sampled at regular intervals.

Pu spot size and Pu concentration data are computer logged and manually recorded. Autoradiographs are retained on colour film.

Grain size

Grain size is measured on the same samples as Pu Spot size. Measurements performed on ceramography samples according to ASTM-E112 are recorded in ceramography report.

Fuel rod

Visual inspection

Visual inspections of all rods are carried out for surface finish and weld appearance (100% inspection). There should be no clad defects greater than the specified limit or discoloration of welds. Additional overinspection of rods sampled at random is carried out by the customer. Results of inspection are manually recorded.

X-ray inspection of rods

Full length x-rays are taken of every rod manufactured in MDF (100% inspection). The full length x-ray allows inspection for the presence of the correct components, the absence of gaps in the fuel column, the absence of unintended materials and the absence of significant fuel faults.

The x-radiographs are also used to check plenum length using a ruler and the results are manually recorded for every rod. The plenum length must be within specified limits.

Additional high resolution X-radiography of top girth and seal weld zones is also undertaken on every rod - this is used to ensure the welds are sound and meet specified limits. Image quality indicators are included in each radiograph to demonstrate the required definition has been achieved.

Results are recorded on radiographs.

Weld metallography

Examination of one metallographic test sample is carried out each day for cracks and penetration depth. Results are manually recorded on metallographic report and control document.

Helium leak detection

All rods are tested for leaks using a mass spectrometer. All rods must meet the specified requirements.

A pass/fail result is manually recorded for each rod on the control document.

Rod surface contamination (smear and fixed)

All rods are checked for both fixed and loose contamination to allow out of glovebox working. Results are manually recorded.

Rod length

The length of each rod is measured on a calibrated transducer. The length must be within the specified limits. Results are manually recorded on computer and the control document (100% inspection).

Rod straightness

Each rod is inspected on a table for straightness (100% inspection). The lift-off from the table must be less than the specification limit. Results are manually recorded on the control document.

Weld region - diameter check

All top girth welds are tested using a ring gauge for weld diameter (100% inspection). A pass/fail result is manually recorded for each rod on the control document.

Helium pressure test

Pressure test equipment automatically displays the internal pressure while end cap seal weld is completed. The value is manually recorded on the control document.

End Plug Seal Corrosion Resistance

Autoclave test according to ASTM-G-2 of one test sample is carried out per week followed by visual examination of the sample. Results are manually recorded on control document.

Wrong Enrichment Detection

Each rod is inspected for pellets of the wrong enrichment (100% inspection). Results are automatically recorded on the scan output.

Fuel assemblies

The following checks are carried out on all assemblies:

Visual, length, bow, tilt, end squareness, fuel rod gaps, fuel nozzle gaps, grid spacer locations, the control rod fit. Automatic recording of bow, tilt and rod to rod gaps is provided. Other gauging manually recorded.

APPENDIX 3

Fuel Rod Failure Mechanisms

In designing fuel assemblies, in addition to a very low manufacturing defect rate (resulting in direct clad failure), allowance must be made for a small number of isolated failures during Conditions I and II (steady operation, start-ups, shutdowns, mild transients, etc) and also for small numbers of failures under Conditions III and IV (fault and severe accident conditions). In order to assess the potential for fuel rod failure, a number of fuel clad integrity criteria have therefore been derived covering the following processes and parameters:

1. clad stress
2. pellet-clad interaction (PCI)
3. clad strain
4. clad wall-thinning
5. clad collapse
6. clad fatigue
7. fuel rod fretting
8. clad oxidation
9. clad hydriding
10. clad embrittlement
11. clad melting
12. fuel melting
13. rod power
14. rod internal pressure
15. rapid energy deposition.

These criteria cover those mechanisms which could lead to failure during the lifetime of the fuel in the reactor and which may be assessed by calculational means.

Fuel rod design calculations are performed to demonstrate that, under Conditions I and II, the criteria outlined above are not breached and hence fuel rod failures will not occur as a result of these effects. The criteria and restrictions applying are described below. For each item, the criteria are explained and justified and the fuel and clad parameters which influence the failure mechanisms are discussed.

(i) Clad Stress

Rapid local power increases can lead to an excessive rate of pellet thermal expansion which cannot be fully accommodated by creep of the clad. This leads to the generation of high circumferential stresses in the clad which can cause clad yielding and ultimately failure due to rupture.

The calculation of clad stresses against the failure criterion takes into account the influence of uncertainties in fuel and clad manufacturing parameters and material properties. All parameters which influence either fuel temperature (and hence determine pellet thermal expansion) or the mechanical response of the cladding are potentially significant. The key items assessed are fuel diameter, fuel density, fuel thermal and mechanical properties, clad diameter, clad thickness and thermal and mechanical properties. The possibility of stress intensification due to the presence of pellet chips must also be assessed.

(ii) Pellet-Clad Interaction (PCI)

During power increases, fuel temperatures rise and the fuel expands. If the fuel-clad gap is closed then this will induce high stresses in the clad. Although the possibility of failure by conventional yielding (when the clad stress exceeds the yield stress) is considered by a separate criterion (see above), under some circumstances failure may occur at stresses below the yield stress due to stress corrosion cracking. For this reason, additional criteria are required, and it is found that the magnitude of local power increase is a suitable criterion for this purpose. Clad failure is thus prevented by limiting the transient increase in local rod power to that specified by the PCI criterion at the applicable conditions.

Parameters influencing the susceptibility to PCI failure are similar to those for the clad stress failure criterion (see (i) above).

(iii) Clad Strain

Clad failure due to uniform clad strain is prevented by limiting the total tensile creep hoop strain in the clad relative to the unirradiated state, and by limiting the tensile increment of total plastic (instantaneous plus creep) hoop strain accrued during any transient event relative to the steady-state condition prior to the transient. These criteria apply to strain values averaged around the clad circumference. The criterion is based on the results of tensile and high strain rate biaxial tests on irradiated Zircaloy-4 tubing. In practice, under reactor conditions, strain will be accumulated at a slower rate, and the limit set is therefore a conservative choice as a clad integrity criterion, since it represents a value considerably below that at which failure would actually be expected to occur.

In the methodology used for calculating clad strains it is found that three parameters account for over 95% of the total creep strain uncertainty, namely fuel density, clad inner diameter and pellet outer diameter.

(iv) Clad Wall-Thinning

Short term cyclic power variations (due, for instance, to daily load following operation) can impose a large number of stress and strain cycles on a fuel rod if these variations occur over a significant fraction of the total irradiation time. If this takes place whilst the fuel is cracked and in contact with the clad, then the fuel cracks will open as the power rises, closing again as the power falls. The frictional force between fuel and clad will be greater when the pellet is expanding and pushing out the clad than when the pellet contracts allowing the clad to contract also. This can lead to the section of clad directly over a fuel crack being stretched plastically as the fuel expands and then the whole of the clad relaxing freely as the fuel contracts. Repetition of this process over a large number of cycles is known as circumferential strain ratchetting. This can lead to significant clad wall thinning directly over a fuel crack, which can cause the clad to fail due to exhaustion of ductility. Clad failure is prevented by limiting the local level of wall thinning due to circumferential strain ratchetting relative to the nominal wall thickness. Fuel clad thickness is the main parameter influencing this failure mechanism.

(v) Clad Collapse

When a newly-loaded fuel rod is being taken to full power for the first time, a large radial gap exists between the fuel and the clad. A differential pressure always exists between the coolant pressure and the rod internal pressure, and if this were to cause the clad to collapse onto the fuel pellets then "wrinkling" of the clad could result. Additionally, the possibility of clad collapse into the plenum region of the rod must be considered. Failure is prevented by ensuring that the combinations of pressure, temperature and time experienced by the clad are not sufficient to cause instantaneous collapse when the core is first pressurised or creep collapse during the anticipated in-reactor lifetime of the fuel rod.

The main manufacturing parameters which have an influence on the calculation of clad collapse probability are: the initial wall thickness of the clad and its creep resistance, the fuel-clad gap size (determined by the clad inner diameter and the pellet outer diameter), the fill gas pressure, and the densification behaviour of the fuel.

(vi) Clad Fatigue

Short term cyclic power variations due, for instance, to daily load following operation can impose a large number of plastic strain cycles on the fuel clad. A much larger number of cycles can be imposed due to grid frequency variations, although the magnitude of the stress cycles is generally lower in these cases. These modes of operation can cause failure of the clad due to fatigue if the combination of stress range and number of cycles is sufficiently onerous. In practice, the probability of fatigue failure is governed almost exclusively by reactor operating conditions, with only a very weak dependence on fuel and clad manufacturing parameters.

(vii) Fuel Rod Fretting

As irradiation proceeds, relaxation of grid springs and reduction of the clad outer diameter (due to creepdown) both occur, and act to reduce the restraining forces between the dimples and the fuel rod. This can lead to relative motion between the clad and the dimples, which in turn can cause wear damage to the clad outer surface. Failure is prevented by limiting the loss of clad thickness due to wear between grids and fuel rods relative to the nominal clad wall thickness. This limit is taken as a guide in evaluating clad imperfections at the manufacturing stage. The methodology assesses the possibility of failure through a number of distinct causes of fretting damage, including: flow-induced assembly vibration, fluid-elastic instability, debris-induced wear, and grid/rod fretting at the bottom grid.

For none of these cases do fuel or clad manufacturing parameters have any significant influence. Rather, failure probability is a function of assembly fabrication, and, for the case of debris fretting, to reactor operation and maintenance.

(viii) Clad Oxidation

The outer surface of the cladding is progressively oxidised by the primary cooling water. High levels of oxidation can reduce performance and lead to clad failure. This occurs when such a reduction in the wall thickness has taken place, due to loss of metal to the oxide phase, that the clad can no longer withstand the stresses and strains which are imposed upon it. Clad failure is prevented by limiting the clad oxide thickness. This in turn limits the loss of wall thickness due to clad oxidation and thus is consistent with the loss of wall thickness allowed for as a result of manufacturing defects.

The magnitude of clad corrosion is determined mainly by the fuel duty and by reactor primary coolant chemistry, with fuel and cladding manufacturing parameters having only minor influence.

(ix) Clad Hydriding

The waterside oxidation of Zircaloy generates hydrogen, which may either escape into the primary coolant, or else be absorbed into the clad to form platelets of zirconium hydride. Such platelets, which may also be formed by uptake of hydrogen on the inner surface of the clad, lead to embrittlement of the material, making it more susceptible to failure. A limit is set for the hydrogen uptake. A substantial amount of testing has been carried out to demonstrate that cladding mechanical properties remain acceptable with considerably higher hydrogen levels, making the criterion somewhat conservative.

In assessing hydrogen uptake against the failure criterion, the major source comes from the oxidation of the clad by the primary coolant, which, as discussed above, is insensitive to fuel and clad manufacturing parameters. An additional source comes from any moisture present in the fuel pellets which could react with the cladding inner surface. This is controlled by limiting the moisture content of the fuel rod during manufacture. It should also be noted that hydriding is observed in many cases of fuel failure but that this is secondary hydriding resulting from primary failure (due to another cause) leading to water ingress and hydrogen generation from steam reactions. Primary hydriding failure is much less common.

(x) Clad Embrittlement

When the heat flux across the clad reaches a critically high value, a thin layer of steam will be produced over areas of the clad surface. This is known as Departure from Nucleate Boiling (DNB). The steam acts as an insulating layer and has the effect of raising the clad surface temperature. Above this critical heat flux, boiling is unstable and partial film boiling or transition boiling may result. Assessment of the DNB ratio depends strongly on reactor fuel duty and on the thermal hydraulic characteristics of the plant, but only weakly on fuel and clad manufacturing parameters.

(xi) Clad Melting

The potential exists for direct clad failure to occur due to excessive clad temperatures leading to clad melting. The melting point of Zircaloy is around 1850°C and therefore a temperature criterion to prevent melting would be set at a level comparable to this value. However, by meeting the embrittlement criterion (see above) clad surface temperatures will be maintained within a few degrees of the water saturation temperature (around 345oC at primary circuit pressure). This criterion is therefore much more restrictive than a criterion based on clad melting considerations, and no additional evaluation is necessary.

(xii) Fuel Melting

Excessive fuel temperatures can lead to fuel melting at the pellet centre (always the hottest region) which could generate large fuel strains due to the significant volume increase associated with melting. Fuel melting itself can also lead directly to clad failure as a result of interaction between molten fuel and clad. Rod power and burnup are the most important parameters determining temperature, but sensitivity analyses against a number of manufacturing parameters are included in the methodology. These are: fuel density, clad inner diameter, pellet outer diameter, fill gas composition and pressure, fuel stoichiometry, fuel plutonium content and clad creep and plasticity. Together with code modelling uncertainties, these parameters are found to account for over 95% of the overall uncertainty.

(xiii) Rod Power

In addition to the direct limit on fuel temperature, a second limit is imposed, on rod power, to prevent the possibility of fuel melting. A limit is set, in terms of kW/m, for the power, local to any position on a rod. The power distribution in a reactor is a function of its operation, assembly loading pattern and thermal hydraulics. The only manufacturing parameter of influence is the fuel fissile content (uranium or plutonium enrichment).

(xiv) Rod Internal Pressure

A third criterion which is imposed to remove the possibility of fuel melting concerns the gas pressure inside the fuel rod. Fuel temperatures are dependent to a significant extent on the size of the fuel-clad gap, since an open gap often has a large temperature drop associated with it. After some months of operation the initial fuel-clad gap is removed due to a combination of pellet swelling and clad creepdown. Normally, the gap then remains closed throughout the remainder of the irradiation. If, however, the rod internal pressure is greater than the external coolant pressure, then the clad may creep outwards rather than inwards. This could cause the size of an open gap to increase, or a closed gap to re-open. Thermal feedback can then take place, as higher fuel temperatures lead to increased fission gas release which in turn causes the rod internal pressure to rise further. Such feedback is prevented by requiring the rod internal pressure to remain below the coolant pressure.

Many fuel and clad manufacturing parameters have an influence on the fuel-clad gap size and/or the rate of fission gas release, and must therefore be assessed in relation to this criterion. Analysis has shown that the following parameters contribute over 95% of the total uncertainty arising from manufacture: plenum length, clad inner diameter, pellet outer diameter, initial fill gas pressure, total gas content, fuel density, and fuel grain size. Other uncertainties, on reactor power distributions and on code modelling are also assessed.

(xv) Rapid Energy Deposition

As the fuel enthalpy rises, so temperatures increase and the fuel expands which may lead to clad failure due to pellet-clad interaction (PCI). This process is normally covered by the PCI criterion (see above). However, in transients which are short compared to the thermal time constant of the fuel (such as rapid reactivity insertion accidents), the PCI criterion cannot be applied, since this is based on experimental power ramp data with relatively slow power increases, and has not been proven to be applicable to very fast power rises. An alternative criterion is therefore required to cover PCI failure during transients of such short duration, and a direct criterion based on the fuel specific enthalpy is the most convenient way of achieving this. Failure is prevented by limiting the Radial Average Peak Fuel Enthalpy (RAPFE) at any position along the rod. This limit is based, conservatively, on results from rapid power tests conducted in a number of facilities in the US, France and Japan. Calculation of peak enthalpy values against the failure criterion are carried out conservatively using specialised code packages.

The results are relatively insensitive to uncertainties in fuel or clad manufacturing parameters. However, the only manufacturing parameter of influence is the fuel fissile content (uranium or plutonium enrichment).

Table 1 Mox Fuel Pellet Lot Numbers with Falsified Data

Location	Lot	Assembly	Type of Falsification
In Japan	P783	005, 006	Type b - copying within spreadsheet, 47 exact cylinders
In Japan	P814	006, 007, 008	Copying from different part of spreadsheet for Lot P810
In Japan	P824	005, 006	Type a - copying, 308 matches with Lot P823
At Sellafield	P855	009, 011, 012	Type a - copying, 590 matches with Lot P853
"	P892	009, 011, 012	Type a - copying, 585 matches with Lot P881
"	P908	009, 010, 011	Type a - copying, 559 matches with Lot P898
"	P912	009, 010, 011	Type a - copying, 554 matches with Lot P900
"	P973	-	Type a - copying, 573 matches with Lot P965
"	P974	-	Type a - copying, 101 matches with Lot P973
"	P988	-	Type a - copying, 565 matches with Lot P970
"	P990	-	Type a - copying, 600 matches with Lot P971
"	P992	-	Type a - copying, 566 matches with Lot P985
"	P993	-	Type a - copying, 562 matches with Lot P990
"	P996	-	Type a - copying, 566 matches with Lot P994
"	P997	-	Type a - copying, 542 matches with Lot P991
"	P999	-	Type a - copying, 595 matches with Lot P972
"	P1001	-	Type a - copying, 592 matches with Lot P957
"	P1003	-	Manual Check - 14 identically sized pellets, see Note 1
"	P1007	-	Type a - copying, 548 matches with Lot P1000
"	P1008	-	Type a - copying, 539 matches with Lot P1000
"	P1009	-	Type a - copying, 535 matches with Lot P1002
"	P1015	-	Type a - copying, 541 matches with Lot P1011
"	P1018	-	Type a - copying, 558 matches with Lot P1011
"	P1021	-	Type a - copying, 537 matches with Lot P1019
"	P1023	-	Type a - copying, 530 matches with Lot P1021
"	P1024	-	Type a - copying, 511 matches with Lot P1019
"	P1026	-	Type a - copying, 522 matches with Lot P1025
"	P1027	-	Manual Check - 11 identically sized pellets, see Note 1
"	P1037	-	Manual Check - 12 identically sized pellets, see Note 1
"	P1039	-	Type b - copying within spreadsheet, including 23 identically sized pellets, see Note 1
"	P1046	-	Manual Check - 14 identically sized pellets, see Note 1

Note 1

Repeated line is the same across all five lots, P1003, P1027, P1037, P1039 and P1046. The diameter readings which are repeated in each of these Lots are 8.185, 8.187 and 8.189 mm.

Note 2

See Section 1.4, paragraph 9, for details of the types of falsification referred to above.

Table 2 Quality Characteristics relating to Fuel Pellet

Fuel pellet quality characteristic
Shape, dimensions
Outer diameter
Length
End profile
End squareness
Surface roughness
Surface condition -
Chips
Cracks
Other surface characteristics
Cleanliness
Stoichiometry -
(U + Pu) content
Pu fissile content
U 235 content
Pu Isotopes
Impurities
Residual gas
Equivalent hydrogen content
Density
Thermal stability
Microstructure
Grain size
Pu distribution
Pu solubility

Table 3 Quality characteristics relevant to Fuel Rod

Fuel rod quality characteristic
Rod identification
Components, fill gas identification
Cleanliness and freedom from damage of parts/assemblies
Dryness of cladding tubes welded at one end
Fuel column -
Length
Fuel stack arrangement
Fuel weight
Moisture content in fuel rod
Fill gas composition and initial rod internal gas pressure
Leak tightness
Dimensional and Visual conformance -
Rod outer diameter
Minimum clad wall thickness
Rod length
Rod straightness
Girth weld diameter
Seal weld inspection
Rod surface
Rod decontamination -
Wipeable alpha contamination
Fixed alpha contamination
Content of fissile material
Pellet gaps/pellet chipping within rod