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Mike T. Lesar
Acting Chief,
U.S. Nuclear Regulatory Commission
Rules and Directives Branch,
Division of Administrative Services,
Office of Administration
Mail Stop T6D59
Washington, D.C. 20555

May 21, 2001

Re: Greenpeace comments regarding the Nuclear Regulatory Commission's (NRC) scoping process in preparation for the completion of the Plutonium (MOX) Fuel Environmental Impact Statement (EIS)

Dear Mr. Lesar:

I submit the following on behalf of Greenpeace Inc. as our initial written comments regarding the Nuclear Regulatory Commission's (NRC) scoping process in preparation for the conducting of the Plutonium (MOX) Fuel Environmental Impact Statement (EIS).

Can you please see to it that I am placed on all NRC 'stakeholder' lists as the Greenpeace point of contact for this issue.

I thank you in advance for your consideration of the enclosed document.

Sincerely,

Damon Moglen

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Mike T. Lesar
Acting Chief,
U.S. Nuclear Regulatory Commission
Rules and Directives Branch,
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Mail Stop T6D59
Washington, D.C. 20555

May 18, 2001

Re: Greenpeace comments regarding the Nuclear Regulatory Commission's (NRC) scoping process in preparation for the completion of the Plutonium (MOX) Fuel Environmental Impact Statement (EIS)

Dear Mr. Lesar:

The following are the initial written comments from Greenpeace Inc. regarding the Nuclear Regulatory Commission's (NRC) scoping process in preparation for the conducting of the Plutonium (MOX) Fuel Environmental Impact Statement (EIS).

Greenpeace is an international environmental and anti-nuclear organization with offices in over 30 countries and over 2.6 million supporters world-wide. In the United States, Greenpeace Inc., based in Washington, D.C., has some 250,000 supporters--including those living in areas which would be effected by the proposed Federal actions involved in this policy. Greenpeace has worked on nuclear issues involved in this policy for over a quarter century and currently runs campaigns on nuclear power, plutonium, nuclear waste, and nuclear proliferation issues.

For the record, Greenpeace strongly opposes the separation and use of plutonium under any circumstances. Given that the consistent use of plutonium has been for the construction of nuclear weapons, Greenpeace holds that a complete ban on the separation and use of all plutonium is required in order to guarantee nuclear non-proliferation. With specific regard to the fabrication and use of MOX, Greenpeace holds that these processes clearly endanger the public health and environment while also creating a massive network of facilities and activities all lending themselves to the uncontrolled spread of weapons-usable plutonium. With regard to the proposal to use MOX to disposition plutonium arising from the U.S. weapons program, it is clear that direct immobilization of these materials is superior at all levels: environment and public health protection, economics, and the rigorous demands of true nuclear non-proliferation and proliferation resistant disposition.

NRC Should Extend Comment Period

Regarding this scoping process, Greenpeace wishes to join with numerous other NGOs and individuals in requesting that the comment period for public review and response to these documents be extended. Access to NRC documents has been difficult and the documents themselves unwieldy and confusing. In addition, information that has been provided requires a significant amount of time to consider. And, it is clear that crucial information is missing and must be made available if real public review and comment is to occur. Taken together, all these factors argue for an extension of the public comment period.

NRC Should Discontinue Scoping Process Pending Comprehensive Review of Disposition Program

Greenpeace also contends that any NRC action, preliminary scoping or the actual conducting of an EIS, is premature and unjustified for the following reasons:

1. Such NRC action presupposes that this program will go ahead with Russia and the U.S. acting simultaneously to secure and disposition plutonium. At this point, it is clear that Russia is not prepared to act simultaneously and in parity with the U.S.. Nor are international funding mechanisms in place to assure Russian ability to construct and operate the necessary facilities even if Russia were committed to doing so. Given this situation, no licensing, let alone actual construction and action, should occur.

2. In statement and action, the new Bush Administration has called into question U.S. government commitment to a "dual track" approach on plutonium disposition. Given that the Administration has defunded the immobilization track, and given that the DOE's Record of Decision called for a dual track, it is clear that the disposition program is undergoing radical and far reaching change. Under the circumstances, a comprehensive review of the program is required prior to further NRC consideration of any program aspects.

Accordingly, we believe that the NRC should immediately discontinue any further review of this project pending a comprehensive assessment by the relevant government agencies of this entire disposition program.

NRC Must Guarantee that Scoping Process Involve the Broadest Review of Issues and Assure Transparence of All Relevant Information

-Full development of "No Action" alternative
Given that there are clear and significant potential environmental, public health and proliferation impacts from the proposed actions, NRC must fully develop and advance the "No Action" alternative. This is all the more necessary given the failure of the government to maintain a "dual track" approach to disposition--a failure which is likely to plunge this program into continued review thereby rendering the "No Action" alternative as the likely status quo

-Full assessment of all issues relating to MOX Fuel Fabrication Facility (MFFF)

*The NRC must provide all technical data relating to the technology to be used

*The NRC must provide and review all operational experience of the DCS partners in the construction and operation of such a facilities--in particular, full review of COGEMA MOX-related facilities including MFFFs at Cadarache, MELOX, and Dessel/Mol and plutonium handling and processing facilities at la Hague, Marcoule, and Cadarache,

*The NRC must provide and review all fuel specification and quality control procedures.
In recent years the issue of plutonium MOX fuel Quality Control and Production standards have become highly controversial. MOX fuel manufactured by British Nuclear Fuels, Belgonucleaire and Cogema have all come under suspicion of falsification of MOX fuel QC data. Investigating these issues, Greenpeace has compiled evidence that falsification of QC is more a symptom of an underlying problem, than the problem itself. In a report submitted to Fukushima District Court, Japan, on December 26th 2000, we highlight the problems with MOX fuel manufacture at the Belgonucleaire MOX plant, P0 (this paper is attached below as part of this submission to the NRC as Annex I). One of the principal conclusions is that the Cogema/BN MOX technology, MIMAS, is incapable of producing MOX fuel to a consistently high standard of quality, including in important areas such as homogeneity. We would request that the generic points raised in that paper, attached be considered by the NRC in its assessment. Given the fundamental problems at the BN MOX plant we note with concern that BN is a contractor to the U.S. government for the design of the MOX plant to be built in South Carolina. The production of MOX fuel in the plant as designated, based as it is on the Cogema Melox plant will guarantee that production standards will be low, QC will be low, and the final product, MOX fuel will increase the risk of catastrophic nuclear accident. Failure by the NRC (and Department of Energy) to conduct a thorough review of MOX QC and production standards would be to compromise nuclear safety to an unacceptable degree.

*The NRC must fully provide and review data relating to the impacts of processing and handling weapons-grade Pu as reactor fuel. Where there is no data, the NRC must fully provide all assumptions made about these impacts and the degrees of uncertainty associated with calculations intended to "model" the use and handling and response of weapons grade plutonium.

*The NRC must fully provide and review all procedures for the fabrication of the lead test assemblies: this should include review of the facilities to be involved, their records, quality control requirements and guarantees, and the transport implications

*The NRC must review all liability issues stemming from MFFF activities

*The NRC must fully provide and review all information regarding waste stream implications for the operation of MFFF facilities and all related Pu materials. For example, full provision and review of the means by which the millions of gallons of high-activity alpha contaminated liquid wastes arising from "plutonium shining" will be handled and dispositioned. This review can and

should involve all wastes arising from MFFF operation as well as the decommissioning and eventual storage of MFFF and all related facilities.

*NRC must conduct a complete environmental justice review of the proposal to site the MFFF in the Southeastern U.S.. This review must include an analysis of communities surround the MFFF as well as those potentially affected down-wind, and down-stream communities. Communities along all transport routes must also be taken into account. Siting of the MFFF and related activities appear to be further examples of placing such dangerous facilities and activities in minority and economically and politically disadvantaged communities.

*The NRC must assure that a comparison is made between all potential impacts of MFFF activities and those involved in direct immobilization

-Full Assessment of All Activities Relating to MOX Fuel Use Stemming from MFFF Operation

*Evaluation of MOX fuel use should not be generic: the NRC must conclude comprehensive evaluation of MOX fuel use based on site/reactor specific analysis

*In order to comply with NEPA, the NRC must assess MOX fuel use on a site specific basis. The agency must use site specific analysis in order to adequately address potential environmental and public health impacts stemming from the transport, storage, and use of MOX at any given site.

*In order to comply with NEPA, the NRC must assess MOX fuel use on a reactor specific basis. MOX fuel use in reactors involves complex operations issues. It is technically inappropriate and legally unacceptable to conduct this review on a generic basis.

*The NRC must fully discuss and evaluate its consideration of Duke's "ice condenser" reactors. Not only are these reactors inappropriate as "reference reactors" in a generic impact assessment, they should specifically be excluded given their clear safety inadequacies--shortcomings that could be all the more pronounced given MOX fuel use. These reactors should certainly be excluded from consideration for MOX fuel use.

*The NRC must fully disclose and review all materials on MOX fuel handling and use. Various statements have been made by the NRC and DOE regarding the extensive experience of MOX fuel handling and use--all such claims should be fully documented by the provision of such materials for public review.

*The NRC must fully disclose and review all information regarding the experience of the DCS partners in the handling and use of MOX fuels. This information should include full review of the problems DCS partners have experienced with the quality control and fabrication of their fuel, its operational characteristics in reactors, its transports, and its storage pre- and post-use in reactors.

*The NRC must fully disclose and review all information relating to impacts of MOX fuel use on workers involved in the transport, handling and use of MOX. This should include the potential increase in dose to workers, etc.

*The NRC must fully provide and review all information relating to impacts of MOX fuel use on the general public potentially effected by the transport, handling and use of MOX. This should include, for example, the potential impacts of a MOX fuelled reactor accident.

*Given the weapons utility of the Pu contained in MOX, the NRC must fully provide and review all security measures required for the secure transport, storage and use of MOX. For example, the NRC must fully discuss the additional requirements for security around transports and at reactor sites in order to secure direct-use nuclear weapons material. This review should also assess the implications for terrorist activity in the US around these actions as well as the implications of such a domestic policy on US non-proliferation policy abroad (the U.S. has of course not encouraged reprocessing and Pu use abroad)

*The NRC must fully disclose and review all liability issues raised by MOX transport, storage and use at commercial reactor sites.

*The NRC must fully disclose and review all issues relating to the transport of MOX

*The NRC must fully address all aspect of the waste streams generated by MOX use--this should include issues relating to the storage and used MOX at reactor sites as well as its eventual disposition.

* NRC must conduct a complete environmental justice review of the proposal to use MOX in reactors in the Southeastern U.S.. This review must include an analysis of communities surrounding the actual reactors to use MOX as well as those potentially affected down-wind, and down-stream communities. Communities along all transport routes must also be taken into account. Use of MOX and related activities appear to be further examples of placing such dangerous facilities and activities in minority and economically and politically disadvantaged communities.

-Full Assessment of Disposition of Waste arising from MOX fuel use

*The NRC must fully disclose and evaluate options for the disposition of spent MOX fuel. In particular, the NRC should clarify whether or not such material will be reprocessed and if so where and with what impacts. And, if it is to be directly stored, where, under what provisions, and with what environmental, public health, and security implications.

*The NRC should fully disclose and evaluate the DCS partners experience with the disposition of used MOX.

*The NRC should fully disclose and evaluate all transport implications stemming from the disposition of spent MOX.

*The NRC should fully disclose and evaluate all security implications stemming from the disposition of MOX given its Pu content.

*The NRC should fully disclose and evaluate all liability considerations involved in the storage and disposition of spent MOX

*The NRC should fully evaluate environmental justice issues raised by its presumed storage of these nuclear wastes in the Southeastern U.S.

-Other Issues

-Given that the NRC intends to license the MFFF, it should also maintain responsibility through operation and decommissioning phases of this program.

-Greenpeace holds that a supplemental EIS (SEIS) should be required if Duke or any other utility seeks a license amendment to use plutonium fuel. A SEIS should be specific to the reactor to be used and should include all ancillary facilities and processes involved. We believe that this can and should be made clear in the course of this NRC evaluation.

---End---

Enclosure: Annex I

Annex I

MOX PRODUCTION STANDARDS AND QUALITY CONTROL AT BELGONUCLEAIRE AND THE IMPLICATIONS FOR REACTOR SAFETY IN FUKUSHIMA-1-3

Submission to the Fukushima District Court, Fukushima City, Japan

Authors: Dr Frank Barnaby, Oxford Research Group/Shaun Burnie, Greenpeace International

December 26th, 2000.

INTRODUCTION

This paper is intended to highlight some of the important issues of plutonium Mixed Oxide (MOX) nuclear fuel fabrication, in particular production standards, quality control and the implications for reactor safety. Specifically, this paper focuses on MOX fuel produced by the Belgian fuel fabricator, Belgonucleaire, and intended to be used by Tokyo Electric Power Company (TEPCO). The document written has been submitted to the Fukushima District Court as evidence on behalf of Tokyo plaintiffs seeking an injunction against the loading of 32 MOX fuel assemblies, manufactured by Belgonucleaire, and transported to Fukushima-1-3 (power plant one, unit 3) in September 1999. The MOX fuel was due to be loaded into the reactor during the first few months of 2000. However, a scandal involving the falsification of quality control data by British Nuclear Fuels (BNFL) for MOX fuel delivered to Japan for use in another reactor, operated by Kansai Electric Power, (KEPCO), forced a delay in all MOX plans in Japan.

During the last 12 months, evidence has emerged that the problems that led to the falsification of MOX fuel quality control data at BNFL, may also have been experienced at Belgonucleaire. This paper will lay out the author's analysis that MOX fabrication itself has inherent technical difficulties, including at Belgonucleaire. Given the importance in terms of reactor safety of ensuring the quality of the MOX fuel is high, in particular the pellet diameter, enrichment, and homogeneity, we conclude that present quality control standards at Belgonucleaire are inadequate. We summarize reactor safety implications of MOX fuel use, and specifically address the importance of pellet diameter in terms of the threat to the safety of Boiling Water Reactors (BWR) in general, and Fukushima-1-3 in particular. Taking into account all these factors we conclude that to proceed with the loading of the 32 assemblies of MOX fuel as intended by TEPCO in April 2001, cannot be justified.

PLUTONIUM MOX FUEL FABRICATION IN BELGIUM

In this section we present an overview of the structure and MOX production history of Belgonucleaire.

Two plutonium/uranium Mixed Oxide (MOX) fuel companies operate at the Dessel nuclear site, in the Mol region, near the Belgian border with the Netherlands. Belgonucleaire manufactures plutonium/uranium MOX pellets and fuel rods at the P0 plant. Belgonucleaire is owned by Tractebel - Belgian engineering company, Electrabel - Belgian electrical utility (operator of the country's 7 nuclear reactors); and CEN/SCK - Belgian nuclear research centre. Both Tractebel and Electrabel are part of the French holding company Suez-Lyonaise des Eaux. After pellet production and fuel rod production is completed, the MOX is transported less than 1000 metres to the Franco-Belge de Fabrication de Combustible (FBFC) International assembly plant, where the fuel rods are put together to form an assembly. This plant is wholly owned by FBFC, a subsidiary of French nuclear companies Cogema and Framatome.

Belgonucleaire's production of plutonium MOX began in the early 1960's, with new capacity being added in 1973. The facility manufactured MOX fuel for Fast Breeder Reactors (FBRs), including France's military production reactor Phenix, as well as for Light Water Reactors (LWR), though the actual amount of fuel fabricated for the latter remained relatively small until 1983/84. Ten tonnes of plutonium fuel in total was produced during this ten year period. In 1984, an initiative was launched between Cogema, the French plutonium reprocessing company, and Belgonucleaire, to form the MOX consortium COMMOX. It functions as the commercial agent for all MOX fuel produced by both Belgonucleaire and Cogema. The MOX plant at Dessel was refitted and renamed P0, with an eventual capacity of 35 tonnes plutonium MOX fuel each year. Plutonium MOX fabrication over the next years was largely for French (80%), as well as German and Swiss reactors. From 1996, approximately 70% of Belgonucleaire's fabrication has been for German clients.

In 1995 a contract was signed between the Toshiba Corp. of Japan and COMMOX for the production of plutonium MOX for the Japanese utility Tokyo Electric Power Company, TEPCO. The Toshiba Corp. was the subcontractor for TEPCO, with COMMOX being the vending consortium representing Belgonucleaire. Fuel assembly fabrication was subcontracted to FBFC. The plutonium for the MOX fuel came from Japan's stockpile of plutonium at the Cogema UP3 reprocessing plant, at la Hague, near the port of Cherbourg, Normandy, France. A total of 60 assemblies of MOX fuel have been manufactured for TEPCO, 32 were delivered to the Fukushima-I-3 nuclear reactor in September 1999. A further 28 assemblies are currently stored in Europe awaiting shipment to the Kashiwazaki-kariwa-3 reactor.

BELGIUM MOX PLANTS AND THE LAW IN BELGIUM

In this section we discuss legal issues in Belgium that have prevented Belgonucleaire from building a new modern and automated MOX plant, and the effect this has had on the operation of the older less automated P0 plant during the last five years, including during the production of the MOX fuel for TEPCO.

Over the last ten years the operations of the Belgian MOX industry, specifically Belgonucleaire and FBFC, have been legally challenged in the Belgian courts. In the case of Belgonucleaire, one successful challenge against its operations prevented the doubling of its MOX production capacity. In an on-going case against FBFC, if successful, the plant's license could be withdrawn. Below we summarize in particular the Belgonucleaire case as it has had a direct impact on the

operations of the company, including how its MOX facility, PO, has been operated over the past five years. We conclude that Belgonucleaire, thwarted in its plans to build a new, modern MOX plant, has been forced to seek to upgrade its aging existing facility while operating it near, and in recent years, above, its nominal capacity. These legal factors, combined with the poor production standards and quality control regime, provide a context for the charge that Belgonucleaire would readily be willing to manipulate vital QC data in order to ensure the continued steady production of fuel.) Move this text to the end of this section.

In June 1992, Greenpeace Belgium co-joined a legal challenge against a license granted to Belgonucleaire for its plans to construct a new modern MOX plant, the so-called P1. This facility was intended to increase MOX production capacity to 70 tonnes Heavy Metal each year (tHM/y). Citing that the authorities had failed to conduct a full public consultation with potentially effected communities prior to the construction license being granted, as required by Belgian law. Greenpeace charged that the facility could not be built under the license issued by the Belgian Government. After 4 years the Belgian Supreme Court finally ruled in late 1996 that construction could not take place under the license.

The Belgian Supreme Administrative Court stated in its ruling:

"The Special Commission is the crucial body in the licensing procedure: a negative advise blocks the government to give a license.(...) The Special Commission has to study all the elements, including the consultation of the population and the advise of the concerned municipalities, to prepare the decision of the government...In this case, this substantial regulation was not respected on 2 points. In the first place, the results of the public consultation in the municipality of Mol and the advisors of the municipality of Mol and the Province council were never presented to the Special Commission. At least, the Commission has never considered them, which is the same. Secondly, these elements should have been submitted to the Special Commission before a preliminary advice could be produced." (March 27th 1996)

This decision by the Supreme Court effectively ended the prospects for Belgonucleaire to carry out large-scale expansion of its MOX production capacity at Dessel.

In the eight years since the Belgonucleaire P1 MOX case came to court, the company has made no re-application for a license, which is due to the likelihood that successful opposition would have been mounted that would have blocked a new license from being granted. The effect on Belgonucleaire's MOX business prospects has been significant. The P1 plant, if it had been constructed, would have been a modern MOX production facility, that would have operated almost entirely for foreign clients, including Japanese utilities.[1]

While Belgonucleaire officially stated that operation of P1 would have given it the capacity to produce 70tHM/y of MOX fuel, there is some doubt as to whether this would in practice have meant the combined operation of both the older PO and new P1 plant. More likely instead PO would have been closed, and P1 would have been the sole MOX plant operated by Belgonucleaire. Given the fact that P1 was going to be a more automated MOX plant than PO

[1] see, "rapport pour debat parlementaire: Rapport sur la Gestion du combustibles use en Belgique et l'utilisation du combustible MOX dans les centrales belges" (Report for the Parliamentary Debate: Report on the Treatment of Spent Fuel Elements in Belgium and the Use of MOX Fuel Elements in the Belgium Nuclear Power Plants, Brussels, October 1992, as cited in 'The MOX Industry', Christian Kuppers/Michael Sailer, IPPNW, September 1994.

there would have been a net reduction in employment. This could be enough reason alone why Belgonucleaire was reluctant to openly discuss such options during the early 1990s.

In a similar way to Cogema's Melox plant, the Belgonucleaire P1 plant had incorporated into its design the ability to expand production, beyond the originally stated 40 tHM/y. This was confirmed by Belgonucleaire during its unsuccessful attempt to sell the P1 design to the United States government. Whereas in the original license application for P1, Belgonucleaire requested a capacity of 40tHM/y, by 1997 Belgonucleaire was promoting to the U.S. Nuclear Regulatory Commission (NRC), that the P1's annual capacity was 60 tHM/y.[2]

P1 was to have been based upon the experience gained in the older P0 plant. The same process and equipment technology was to have been used in P1 as that in P0. However, Belgonucleaire has stated that there would have been 'significant' changes,

"...with respect to P0 (and) the equipment arrangement in the plant and some technological improvements as well as some automization." [3]

In addition to admitting that P0 was not fully automated, Belgonucleaire has made it clear that the P1 facility would have had its equipment laid out to the latest standards of industrial engineering design. This would have meant for example that plant ergonomics would have incorporated the latest concepts to maximize production capability. Significantly, one criticism of the discredited BNFL MOX Demonstration Facility (MDF) plant that produced MOX for Kansai Electric is that the ergonomics of the plant led to problems for the operators and workers.

Having failed in its attempt to construct P1, Belgonucleaire was left with only the existing P0 plant to fulfill its orders. Thus Belgonucleaire was forced to resort to maximizing its existing production capacity in an attempt to secure new, but obviously smaller contracts for fuel supply. It has been argued by us before that meeting production targets became a critical factor for MOX manufacture.[4] We argue that in the case of BNFL, the basic inability to manufacture MOX fuel and the small size of the production capacity relative to the contract size (16 tons capacity over two years, for a Japanese contract of 8 tons for Kansai Electric) were a central factor in BNFL's falsification of QC data and the passing of fuel that should have been rejected. (Insert footnote: Rather than the maximum of 6 months that the production of the Takahama-4 MOX fuel should have taken instead it took BNFL 12 months to fabricate the fuel, due to production problems within the plant.)

In the case of Belgonucleaire the situation has been somewhat different as its production record over the last ten years demonstrates (over 378 tHM MOX produced between 1990-1999). Unlike BNFL, which had few contracts for MOX manufacture and was not even able to produce what it had contracts without delays, Belgonucleaire was under different pressures in particular due to its production capacity being fully booked until 2005. This has meant that P0 has been operating at close to licensed capacity for successive years, including during the manufacture of TEPCO

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[2] see, NRC Workshop on Fabrication of MOX Fuel, Rockville, Maryland, March 26, 1997, 'MOX fabrication plant licensing experience', presentation by plant engineering manager Michel Debauche, Belgonucleaire.

[3] ibid, NRC Workshop p.14.

[4] see, 'Fundamental Deficiencies in the Quality Control of Mixed Oxide Nuclear Fuel', Dr Frank Barnaby/Shaun Burnie Greenpeace International, Fukushima City, Japan, March 27th 2000.

MOX in 1997-1999. The nominal capacity of the plant after refurbishment and capacity increase is 35tHM/y, with a license maximum of 40tHM/y. The production of Fukushima-I-3 MOX fuel, coincided with the highest production output in Belgonucleaire's history for three successive years, yielding a total of 110.2tHM. That is, in the three years between 1997-1999, during which the production of Japanese MOX fuel, including for Fukushima-I-3 and Kashiwazaki-kariwa, took place, P0 produced 5tHM in excess of its nominal capacity.

Belogonucleaire would no doubt argue that this is evidence of the reliability of the fuel manufacturing process at P0. However, it also can be argued that this gives the manufacturer little flexibility if it is to meet its customer's delivery requirements and thus failure of fuel and delays in production must be minimized. In addition, Belgonucleaire has admitted that maintenance and repair of equipment cause delays in production. It is for this reason that it has established an interconnection between the two lines for pellet and rod production, which "allows the bypass of some of the part of the equipment...with a reduced impact on the output of the plant." [5]

A legal case still under consideration by the Belgian judiciary concerns the FBFC 5M MOX final assembly plant, located less than 1000 meters from Belgonucleaire and operated by the French company, FBFC International. This case revolves around the construction license granted for the plant. As in the previous case against Belgonucleaire, the plaintiffs, Greenpeace Belgium, has charged that FBFC did not follow the correct procedures for public consultation required under Article 12 and 13 of the Belgian Atomic Law,

Lawyers acting on behalf of the plaintiff have reported to the authors that the case against the FBFC plant license is a stronger one than that in the case of Belgonucleaire's P1. Again the issue of violating the law to prevent public oversight is repeated in connection with MOX production in Belgium.

LIMITED BWR MOX FUEL MANUFACTURE

In this section we point out that BWR MOX fuel, such as that produced for Fukushima-1-3, is more complicated relative to PWR fuel, and that Belgonucleaire has very limited experience in BWR MOX fuel manufacture, and that there are only two BWR reactors in the world currently operating with MOX fuel.

"The MOX FA (fuel assembly) for the insertion in a BWR is in general much more complicated because of the much higher heterogeneity in comparison to PWR." Siemens, June 1999.[6]

The production standards required for the manufacture of MOX fuel are considerably higher than for those of the conventional uranium industry. Not only is this due to the different characteristics of the manufacturing process, including the need for two different oxide powders to be mixed together thoroughly, but also because the fuel itself performs across a range of parameters differently from uranium fuel. As noted by Siemens, MOX fuel intended for use in

5 see, 'Experience and Trends at the Belgonucleaire Plant', Dermaix,Eekhout,Pay and Pelckmans, BN, Dessel, Belgium, June 1999.

6 see, "Advanced Mixed Oxide Fuel Assemblies with Higher Plutonium Content for Light Water Reactors", W. Stach, Siemens AG, Untemehmensbereich KWU, Erlangen, Germany, June 1999.

BWR's require a more complicated process of assembly than that for PWR. This is due to the higher heterogeneity in BWR's, including the need for a larger range of plutonium enrichments relative to PWR MOX fuel. Siemens fuel specialists note that 6 different MOX rod types and 1 additional Gd (gadolinium) poisoned fuel rod (to avoid power peaks around the water channel and to reduce initial criticality) make up the typical BWR 9X9 assembly. TEPCO confirm that there are four different enrichment types in the Fukushima-1-3 MOX fuel assemblies.

Given this additional complexity, it is worth noting that Belgonucleaire, though it promotes itself as the major MOX manufacturer historically, has considerable less experience in BWR MOX production compared with PWR fuel.

Of the 418tHM MOX produced by Belgonucleaire since 1986, only 10% has been BWR fuel. In terms of total MIMAS BWR MOX production, the comparisons are even less favorable. Through the end of 1999, a total of 839 tonnes of MOX had been produced by Cogema's Melox and Belgonucleaire (combined figures for Cadarache are not included, however no BWR MOX fuel is produced at this site), of which 5% was BWR. COMMOX (excluding Cadarache) manufactures MOX fuel for clients in Germany, Switzerland, Belgium and France (and Japan). Out of all the MOX produced by COMMOX only 4% has been loaded in BWR reactors. Prior to the manufacture of the Fukushima-I-3 MOX fuel, Belgonucleaire had only produced commercial BWR MOX fuel for one client in Germany. Belgonucleaire does not have extensive BWR MOX manufacturing experience. Nor can it be said that electric utilities have extensive experience of BWR MOX use. The Fukushima-I-3 reactor will be only the third commercial BWR in the world to load MOX fuel. In total 34.6 tons of MIMAS BWR MOX have been produced by Belgonucleaire for the German power plant, Gundremmingen (two reactors). This corresponds to 228 assemblies, containing 16,843 fuel rods. In addition, a further 7.5 tonnes of MOX were produced for Fukushima-I-3 and Kashiwazaki-Kariwa-3, corresponding to 60 fuel assemblies containing 2752 rods.[7]

MIMAS MOX

In this section we briefly summarize the technology and process stages of MOX manufacture at Belgonucleaire`s P0 facility.

The MIcronized MASter Blend (MIMAS) process was developed by Belgonuclaire to replace the former process used at Dessel that directly blended the UO2 and PuO2 powders. MIMAS is also used by Cogema to produce MOX at the Cadarache and Melox plants. The principal reason for developing MIMAS was to produce MOX fuel soluble enough for the reprocessing of spent MOX fuel in concentrated nitric acid.

The MIMAS process first creates a primary blend, called a Mastermix. PuO2, UO2 and scrap are ball milled for many hours. The primary blend contains about 30 per cent plutonium. The required final plutonium content is achieved by blending, not milling, the primary blend with depleted or natural UO2. MIMAS MOX, therefore, consists of agglomerates of 30 per cent Mastermix in a UO2 matrix. This is different from BNFL's Short Binderless Route (SBR) MOX,

[7] see, Belgonucleaire own data released to Japanese legislators, BN-02-0005-E.

which consists of PuO2, UO2 and recycled scrap milled together to produce MOX of the required plutonium content.

Whereas BNFL's SBR uses a one blending step, MIMAS uses a two blending step's to produce a solid solution of UO2 and PuO2 dispersed in a UO2 matrix. The powder is then pressed into cylindrical pellets, which before sintering are said to be 'green pellets'. The 'green' pellets are passed on a conveyor belt to a furnace 'boat load station' where they are loaded into furnace 'boats' and taken to the furnace where they are sintered in a cycle of about 24 hours in an atmosphere of argon and hydrogen (the gas mixture is 4 per cent hydrogen and 96 per cent argon) to which is added a small quantity of carbon dioxide to control grain growth.[8] The sinter temperature is up to 1,750 degrees centigrade. After sintering, the MOX pellet is in ceramic form. During the sintering process the finely divided particles inter-diffuse to form what amounts to a near-solid solution of uranium-plutonium dioxide (UPuO2).

Conveyors then transfer the pellets to the grinding and inspection stations. They are dry ground using a centerless grinding machine. In the case of PO facility two lines with two grinders are used to perform this task. Boat Unloading and Grinding Lines are designed to deliver the pellets, after they have left the sintering process, in the correct orientation to the grinding machine, which is supposed to accurately grind the outer diameter to the dimensions specified by the customer; the end and radial surfaces are again ground to the dimensional tolerance as specified. The pellets are then passed through an automatic total pellet measurement. This allows the operator to adjust the position of the grinder to ensure the pellets continue to meet the specification. The measurement system includes a mechanism that is intended to eject pellets that are out of tolerance. Before the production of pellets is completed, a largely manual QC inspection is conducted on a range of parameters, including diameter, enrichment, etc. Once the MOX pellets have passed this stage, suitable pellets are put into a pellet store until they are required for the production of reactor fuel rods. Unsuitable pellets are supposed to be recycled.

The fuel rods consist of a stack of MOX pellets encapsulated in a zirconium alloy (zircalloy) sheath that is purged with helium to form a sealed fuel rod, 4-4.5 metres long. The MOX fuel rods are arranged in square arrays with lightweight bracing to form fuel assemblies. The pellet stack in a fuel rod is compressed along the axis of the rod by a spring at the end of the rod.

The fuel rods are inserted into the reactor core as an assembly; the rods are held in geometric (square) array by lightweight spacers to form fuel assemblies for a PWR or BWR nuclear-power reactor. A typical MOX fuel assembly consists of a square array of rods: each 3-metre long rod contains about 300 MOX pellets. For a PWR the array is typically 17 by 17 rods; for the Fukushima-I-3 TEPCO MOX it is BWR assemblies of 8 by 8 rods.

HOMOGENEITY AND THE LIMITS OF ALPHA-RADIOGRAPHY

In this section we highlight the importance of MOX fuel pellet homogeneity, the differences between Belgonucleaire (and Cogema) MIMAS technology and the BNFL SBR method. We

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[8] see, Fujishiro, T., West, J-P., Heins, L., and Jadot, J. J., Overview of Safety Analysis, Licensing and Experimental Background of MOX Fuels in LWRs, IAEA/OECD-NEA International Symposium on MOX fuel cycle technologies for medium and long term deployment: experience, advances, trends, International Atomic Energy Agency, IAEA-SM-358/III, Vienna, 17-21 May 1999.

then highlight the inadequacies of current MOX fuel homogeneity quality control tests, including at Belgonucleaire. We conclude that in this important area, Belgonucleaire MOX fuel is less homogeneous than BNFL manufactured MOX, and that the testing procedures applied to the 32 Fukushima-1-3 assemblies are unable to ensure the quality, and therefore safety, of MOX.

The production of MOX fuel involves the use of an advanced powder technology requiring the mixing, micronizing, pressing, sintering and grinding of two actinide oxides. Experience in other powder processing industries, such as the pharmaceutical industry, suggests that technologies dependent on powder technology are not very reliable, according to our discussions with powder rheologists. Small changes in parameters such as humidity, binder concentration and particle size distribution can affect the powder rheology and thus result in changes in flow rate, poor mixing or powder jams. Such problems are likely to be more severe and more frequent when, as in MOX fuel pellet fabrication, relatively small batches and variable formulations are pelletised. Variations of flow are likely to affect the density and dimensions of pellets and the homogeneity of plutonium distribution in the pellets.

MIMAS MOX fuel proponents claim that because of the double blending, there is good isotopic homogeneity of plutonium in the product, even with plutonium from different origins - light water or gas cooled reactors. BNFL advocates of its technology Short Binderless Route (SBR), however, argue that with ball milling it is difficult to achieve a plutonium agglomerate specification of 400 microns maximum. SBR, they claim, offers a 100 microns maximum and, in practice, there are few agglomerates even as large as 20 - 30 microns.[9] BNFL claim's that it: "has successfully demonstrated that SBR MOX fuel has no significant plutonium-rich regions of more than 20 microns diameter containing more than 30 percent plutonium".

BNFL state that,

"Analysis of Electron Probe Micro-Analysis (EPMA) maps shows that SBR MOX consists of almost entirely a MOX matrix, with less than 1% of spots containing greater than 20 wt% plutonium, for an enrichment of about 5.5% Pu/U+Pu. The Pu-rich regions in MIMAS MOX form a significant fraction of the fuel, about 25%, with regions up to 100 microns in diameter, while the largest Pu-rich regions observed in SBR MOX are seldom more than 30 microns in diameter"[10]

We argue below, however, that the adequacy of the checking procedures does not allow such statements to be substantiated.

In a recent Japanese report from an industry and government funded nuclear research foundation, NUPEC, the size of Pu-rich zones cited above are in fact exceeded[11] Comparing the sets of data for example it is possible to see that agglomorates of pu-rich zones are up 100% larger with MIMAS MOX than with BNFL, with center pellet data showing dimensions of 140 microns, compared with BNFL spots of 70 microns.

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[9] see, Eastman, R. J. and Tod, S., The Microstructure of Unirradiated SBR MOX Fuel, IAEA/OECD-NEA International Symposium on MOX fuel cycle technologies for medium and long term deployment: experience, advances, trends, International Atomic Energy Agency, IAEA-SM-358/III, Vienna, 17-21 May 1999.

[10] Brown, C., BNFL, private communication, November 2000.

[11] see, NUPEC, Report on Fuel Assembly Credibility Substantiation Examination - Mixed Oxide Fuel Irradiation Compilation March 12th 2000.

In this latest research it is possible to make a comparison between homogeneity of MOX fuel made with BNFL's SBR, and analyzed by BNFL, and MOX produced at Belgonucleaire by the MIMAS process, and analyzed at the SCK-CEN research center in Dessel, Belgium. Although there appear to be uncertainties with some of the parameters of the analysis, it is noticeable that in terms of pu-rich zones, "hot-spots", the BNFL MOX fuel has smaller dimensional spots. This is not confirmation that BNFL MOX is problem free in terms of homogeneity, far from it. But it is indication that the MIMAS process used by both Belgonucleaire and Cogema is inferior relative to BNFL SBR in this important area.

The problem of homogeneity is further compounded by the low frequency of QC inspection, (see Table 2 below). Homogeneity of Belgonucleaire MOX pellets is measured by using colour alpha autoradiography in which a thin section is cut from a sample pellet, polished and then placed in contact with a photographic film for some days, developed and examined and the size and number of clumps of silver grains in the film assessed. If colour film is used, plutonium shows up as red, so that plutonium particles appear as red dots. This is the same method used by BNFL.

It appears that only one sample is taken for autoradiography per 13,500 pellets. In a TEPCO report, dated 24 February, it is stated that 32 pellets were checked for homogeneity out of a total of 430,000 (for Fukushima-I-3 reactor fuel). And even for each pellet only a thin slice, representing a very small fraction of the volume of the pellet, is examined. To check only one pellet in 13,500 for homogeneity by autoradiography on only a thin slice of the pellet is inadequate, especially when it is considered that quality control of MOX pellets by necessity needs to be more stringent than of uranium oxide pellets. The Belgian nuclear research center, SCK/CEN, which conducted the analysis cited by NUPEC, and it appears do all alpha-radiography for Belgonucleaire, dispute this. In a response to an earlier paper of ours Verwelt et al state that the,

"MIMAS process is a two-stage blending with thorough micronisation during the first stage. In the final product, occurrence of large, pure PuO2 agglomerates is impossible. During micronisation, all plutonium is mixed with UO2 up to an enrichment of 35%, on sub-micron level. In the finished product, plutonium-rich zones do occur, typically with a diameter between 10 and 50µm, but these are as enriched as the primary mix, with a plutonium-grade of only 35%".

The evidence for this statement however, particularly the claim that the 'occurrence of large, pure PuO2 agglomerates is impossible' is not substantiated. [12]

As already noted, research from SCK show that they themselves find a considerable number of plutonium hot-spots over the 100 micron range, again using only limited alpha-radiography checks. We remain unconvinced that the inspection rate for inhomogeneity conducted at Belgonucleaire/SCK is adequate for a fabrication technology subject to the vagaries of powder flow. Will brief fluctuations in the efficiency of mixing be detected unless substantially all of the pellets are inspected? Do the quality control methods used adequately ensure that pellets do not contain agglomerates with a diameter larger than 550microns, or any other size? On this issue alone we have little confidence in the assurances that MOX fuel is safe to use in reactors.

[12] see, 'Review of the report 'Fundamental Deficiencies in the Quality Control of Mixed-Oxide Nuclear Fuel', Greenpeace International, F. Barnaby/S. Burnie, Marc Verwerft, Peter Vermaercke, Klaas van der Meer, SCK/CEN, Mol, March 20, 2000.

The information given by Verferft/SCK in Belgium suggests that about five MOX pellets per assembly will have an isotopic composition which varies by more than three standard deviations from the mean of isotopic composition. On what grounds do Verwelft et al believe that this number is acceptable from the point of view of reactor safety? In fact, what do Verwelt et al believe this variation means for reactor safety?

Verwelt et al say that 'commercial confidentiality' prevents them giving details of the quality control procedures used by Belgonucleaire to check MOX fuel pellets. This argument is spurious, given the fact that NUPEC has recently published in considerable detail the methodology of QC alpha-radiography, as well as details on the micro-structure of the MOX pellets, including those produced at PO Belgonucleaire.

What the refusal of Belgonucleaire (and SCK/CEN) does however, is prevent independent scrutiny of quality control and quality assurance procedures for MOX. From what we can discover from open sources, the MOX industry relies on the results of limited research trials carried out on fuel produced by different fuel fabrication plants operating under optimal conditions. We believe that it is irresponsible to rely on such activities and dispense with adequate quality control procedures.

PROBLEMS OF DRY GRINDER TECHNOLOGY

In this section we briefly highlight the consequences of the use of dry grinders during MOX pellet manufacture, including the effect on pellet diameter measurement.

During the BNFL/Kansai Electric MOX falsification scandal, it became public that BNFL's method for grinding and the sintered MOX pellets caused the pellets to chip and crack. This, it is suggested by Kansai Electric, was the reason why the laser measurement for all pellets was altered to measure the diameter in a two millimeter central band rather than at both ends and middle. Kansai Electric further explained that pellet diameter adjustment is difficult using a dry grinder, and it is for this reason that a total pellet measurement is carried out. (Footnote: However it has also been pointed out by plaintiffs that BNFL pellets have been reported as being flowerpot or hour glass shape, requiring the company to alter the points on the pellet which are measured during the total pellet measurement.)

The reason for the damage to the surface of MOX pellets appears to be due to the fact that commercial MOX facilities use the dry grinding process. This was not always the case, and may be an example where scaling up production of MOX for commercial use has had a negative impact on the quality of the final product. It is known for example, that MOX production in the past in Japan for the experimental Advanced Thermal Reactor (ATR) Fugen, used a wet grinding process.[13] The uranium fuel industry uses a wet grinding process.

In the fabrication of MOX pellets, the risk of employing wet grinding is that there is an increased risk of criticality as the wet process binds together an amount of plutonium MOX powder.

[13] see, "Operational experiences in MOX fuel fabrication for the Fugen Advanced Thermal Reactor, p.109, T. Okita, S. Aona, K. Asakura, Y. Aoki, T. Ohtani, Japan Nuclear Fuel Cycle Development Institute, Ibaraki-ken, Japan. IAEA-SM-358/3 June 1999 IAEA Conference.

However, the wet grinder has clear advantages over dry grinding in terms of pellet quality. This is due to the fact that the pellet does not come into direct contact with the grinder, but rather is ground to the required dimension by coming into contact with the wet layer that builds up between it and grinder, the so-called 'Michelin Effect'. The interaction between the pellet and grinder during dry grinding is more damaging to the pellet surface than wet grinding. However, the safety risks in terms of criticality posed by the use of a wet grinding process when handling large quantities of plutonium MOX fuel were a significant factor in the commercial MOX producers fuel opting for the dry grinder. As with BNFL, Belgonucleaire and Cogema utilize dry grinders in their MOX facilities.

It is not possible from information so far released by TEPCO to say whether or not pellets that are chipped and cracked produced by Belgonucleaire have forced the company to alter the points at which they measure during the all-pellet measurement. It is worth noting that despite months of investigation by the UK Nuclear Installations Inspectorate at the BNFL MDF, their inspectors were not aware of the changes made by BNFL until it was disclosed in the media.

SCRAP MOX

In this section we highlight that relative to Cogema, Belgonucleaire is less able to recycle scrap MOX fuel, and that this important economic factor for the company could influence the degree to which MOX pellets are rejected.

A feature of all MOX fuel producers has been their efforts to reduce costs by developing technology that can recycle scrap materials collected during the production and QC process. Given the costs of MOX fuel compared with uranium fuel (ranges of 3-9 times higher) this is understandable. Scrap is defined as,

"...generated by the process itself (e.g. centerless grinding fines or sludges), by the rejects (e.g. non conforming pellets) and by the surpluses fabricated within a fabrication campaign before switching to the next fabrication campaign (in-line contingency inventories of MOX powder, pellets and FRs.[14]

It is important to note that Belgonucleaire admits that their scrap contains rejected pellets. It has also stated to TEPCO that the production of MOX fuel for Fukushima-I-3 did not lead to the rejection of any pellets at the manual QC diameter inspection stage. When the campaign size is small compared to the fabrication capacity the surpluses constitute a majority of the scrap arisings. During the two year (1997-98) period of MOX manufacture for Fukushima-1-3 of around 5 tons, in total Belgonucleaire produced nearly 80 tons of MOX fuel. Belgonucleaire will have little control over the amount of scrap that is in the form grinding fines or sludges, or surpluses. Thus the area where they have direct control over is in the number of rejected pellets during the all-pellet measurement and QC manual inspection. The need of a MOX producer to minimize reject pellets is driven largely by economics, and meeting production schedules. This was certainly a factor in the decision by BNFL to pass MOX fuel that should have been rejected, and to falsify QC data. It could very well have been a factor with Belgonucleaire.

[14] see, 'Overview of MOX Fuel Fabrication Achievements', H. BAIFUOT, Mol, Belgium J. VAN VLIET Belgonucleaire, Dessel, Belgium G. CHIARELLI, Cogema, Bagnol-sur-Ceze, France, J. EDWARDS British Nuclear Fuels plc, Sellafield, United Kingdom, S.H. NAGAI, JW Tokai, Japan, F. RESHETNIKOV State Research Center R.F., Moscow, Russian Federation, paper to IAEA MOX conference June 1999.

As the fabrication campaigns are frequently relatively small, adequate management of the scraps is an important consideration both in terms of economics (fabrication cost) and impact on the environment (personnel exposure and waste generation). Belgonucleaire has thus developed technology to recycle the scraps back into the process.

Up to 18 % of the master blend for P0 can contain scrap MOX. This compares significantly with Cogema's modern Melox plant which can accommodate 50 % rejected pellets in the master blend.[15] Both Cogema and Belgonucleaire argue that an advantage over BNFL technology is that the MIMAS process, by being able to re-introduce scrap at primary or secondary blending steps, easily recycles rejected pellets, grinding powder, and other scrap. It should be borne in mind that ease of recycling might influence quality control. If it is harder to recycle, as it is in the SBR process and as it is at Belgonucleaire relative to Melox, there may be pressure not to reject pellets on inspection. There may be a direct connection between rejection (failure) rates and ease and cost of production, an example of how commercial considerations may affect quality control. The limited capacity to recycle scrap highlights further similarities between BNFL and Belgonucleaire.

PLANT WORKER RADIATION EXPOSURE

In this section we discuss the fact that due to the age of the Belgonucleaire`s P0 facility its operating license restricts the percentage of the high-gamma emitter isotope, Americium-241, to a lower fraction than that at more modern MOX facilities. We relate this issue to worker dose factors, and the extent to which this less automated facility on the one hand requires greater manual intervention during production and QC stages, while at the same time under pressure from regulators to reduce worker dose, forces management to limit the amount of inspection and checking done on the MOX fuel.

MOX fuel plants are inherently dangerous facilities, handling as they do large quantities of plutonium in bulk form, including fine powders. They historically have had problems with exposure of their workers to the hazards of plutonium, both through routine exposure to gamma, beta and alpha radiation as well as a result of accidents. Years of concern over inadequate safety standards in the Alkem, later Siemens Brennelementwerk Hanau, (SBH) plant near Frankfurt, Germany, including the internal plutonium contamination of five workers in an accident in June 1991, led to the withdrawal of its operating license in 1994. This facility operated since 1971, dates from the same era as the Belgonucleaire P0 plant. Safety concerns were one of the factors in the state government successfully opposing the opening of the new Hanau MOX plant, despite the fact that the plant was nearly completed at a cost of US$800 million. In Belgium in November 1992, FBFC also suffered a plutonium incident leading to worker internal contamination at its then operating MOX fuel final assembly plant at Dessel, which subsequently led to several months of production delay.

Direct exposure to radiation in MOX production facilities is a highly relevant issue for the operations of P0 at Dessel. As with the older MOX production facilities, including BNFL's MDF, Cogema's Cadarache, and Siemen's Hanau plant, as well as JNC PFPF and PFFF at Tokai-mura, PO worker process plutonium and uranium oxide in so-called glove boxes. The material is

[15] Ibid.

handled in a box held at sub-atmospheric pressure to which plastic gloves are attached with which the workers reach into the boxes. This technique has not changed significantly over the past 50 years. The gloves are the prime weak-point of occupational protection. Although facilities have made modifications to both the degree of automation and therefore a reduction in direct worker handling of the nuclear material they have been unable in the older MOX plants to reach the standards of newer facilities.

Plutonium that is stored several years after reprocessing has increased gamma radiation from the decay of the Plutonium-241 isotope to Americium-241 (Am-241). As Sailer and Kuppers have noted, the additional worker handling required to manufacture MOX fuel pellets has meant that radiation exposure of workers is substantially higher.[16] A critical factor in being able to minimize worker exposure is the amount of shielding built into the plant, and the degree of automation. In both these areas, P0 does not even reach the standards of modern MOX fuel fabrication facilities, such as the Hanau plant that was never granted an operating license. As already noted, the P0 plant, like the old and now closed Hanau plant, began operation in the early 1970's when radio-protection standards were lower than today. The imposition of higher worker protection standards during the last thirty years, since P0 began operation, has forced Belgonucleaire, all be it slowly and reluctantly, to back-fit the plant in an attempt to comply with those standards. While the trend has been higher worker protection standards with lower exposure, the Am-241 content of plutonium being processed by the workers has also increased as the age of plutonium has increased.

A comparison of license limits set by the state regulators highlights that despite backfits, Belgonucleaire has not been able to bring the P0 plant up to modern standards. Within the COMMOX group, consisting of the Cogema plant CFCa at Cadarache, Melox at Marcoule and Belgonucleaire's P0 at Dessel, the relationship between age of plant and license limit in terms of Am-241 exposure is clear (see table1).Older facilities are licensed to process plutonium with a smaller percentage of Am-241. Whereas the Melox plant, designed and constructed during the late 1990's, has been granted a license limit of 3%, Belgonucleaire has been restricted to 1.7%. Thus although the total plutonium tonnage processed during any one year is nearly three times greater at Melox than at P0, the shielding and automation built into the plant gives Cogema greater flexibility in handling a greater range plutonium.

Table - 1 - AMERICIUM 241 LICENSE LIMITS FOR COMMOX FACILITIES

LICENSED PLANT	OPERATING SINCE	LICENSING LIMITS % am-241
BN - PO - Dessel	1973	1.7
Cogema - CFCa - Cadarache	1962	1.5
Cogema - Melox - Marcoule	1995	3.0

Source: MOX fuel use as a back-end option: trends, main issues and impacts on fuel cycle management. Fukuda,Choi,Shani, - IAEA, Vienna; van den Durpel,Bertel,Sartori - OECD Nuclear Energy Agency, France. IAEA-SM-358/I, June 1999.

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16 see, The MOX Industry, K. Kuppers/M. Sailer, ed. J.vande Putte, IPPNW, 1994. It is worth observing that as Japan's stockpile of separated plutonium of around 27,000kg stored at la Hague ages, the Am-241 levels will continue to increase, raising concerns for those in France who will eventually handle during MOX production and transport, as well as those nuclear power plant workers in Japan that will be involved in its eventual loading in reactors.

Belgonucleaire has during recent years been forced to try and reduce worker exposure, while also maintaining production. In fact during the actual production of the Fukushima MOX fuel (June 1997 - December 1997), Belgonucleaire was in the middle of the mechanization of equipment within the plant, begun in 1995. This, according to Belgonucleaire, was intended to improve radioprotection of the production equipment, including the reduction of worker dose levels to below 20mSv/y. It has to be considered that the Fukushima MOX was produced at a plant that did not meet the highest available standards of modern nuclear fuel facilities, and that efforts to backfit these by Belgonucleaire throughout the 1990's can hardly be considered ideal.

The importance of this factor can be further understood when taking into account that the planned P1 plant would have been of modern design, taking into account amongst other things, higher worker protection standards. For the P1 plant, Belgonucleaire intended to attempt to reduce further worker exposure by the use of "hardware solutions like neutron and gamma shields on the glove boxes, installed all fuel storage behind concrete walls, and used separate rooms for operations where significant long stays by personnel are required."[17]

Belgonucleaire has also admitted that for P1 it would seek to reduce direct worker interaction with production equipment through the use of modern software. Automatic inspection for pellet diameter was to be incorporated. In other words, Belgonucleaire would have used the latest designs to maximize the efficiency of the production of the plant, while attempting to comply with stricter modern standards in terms of worker exposure. The commitment of Belgonucleaire to these standards and how successful they would have been in reducing worker exposure in P1 will never be known given that they would have incorporated these into the design of the plant prior to construction, however they certainly would have found it easier to meet these standards in comparison with trying to incorporate them into a plant already constructed, operated and contaminated.

Given all these factors, we can conclude that workers in P0 have to work in an environment where radio-protection is lower than at modern MOX facilities. Because of the age and design of the plant, they have greater direct interaction with the MOX fuel pellets during production, and importantly QC. Under pressure from the regulators to reduce dose rates, Belgonucleaire will look to minimize direct contact with pellets, where it is possible to do so. Manual QC inspection is one such area.

As TEPCO and Belgonucleaire have explained in their literature, inspection and QC control process workers visually inspect MOX pellets for defects and select MOX pellets for QC diameter inspection, as well as other QC checks. While this form of inspection and QC is essential, it is one further point of exposure for the workers at P0. Both the number of pellets selected and the length of time handling the pellets are direct factors in the dose received. Keeping pellet numbers low and reducing handling times are obvious ways of reducing exposure. However, the production standards of MOX plants in general, including P0, are below those of conventional uranium fuel fabrication plants, when it is considered how much more complex and the extra process stages involved to produce MOX fuel. Thus inspection and quality control takes on greater significance. While the number of pellets manually inspected at

[17] Opcit see, NRC Workshop, p.16.

the QC stage is low, the number of pellets visually inspected for appearance is relatively high. For the Fukushima-I-3 MOX pellets a total of 16,827 pellets were manually observed. The radio-protection inadequacies in the P0 plant, relative to modern MOX plants, and the pressure to keep worker dose levels below 20mSV certainly will have been a factor in the accuracy and reliability of pellet observation and QC inspection conducted by the workers in the plant.

WEAKER QUALITY CONTROL BELGONUCLEAIRE RELATIVE TO BNFL

In this section we compare the QC control applied at Belgonucleaire and compare it with that applied by BNFL. We conclude that in important areas related to the quality and safety of MOX, the Fukushima-1-3 fuel has had less robust QC applied, and that quality assurance standards are in general poor at P0.

The BNFL MOX scandal exposed that company's QC and production standards to public scrutiny for the first time. There remains much to be understood about the standards of BNFL: however, only in recent months has it become clearer that the quality control standards applied in other MOX production facilities, including Belgonucleaire, as well as other plants involved in the nuclear fuel business, also have significant problems. These problems should give rise to public concern, concerning as they do the quality of nuclear fuel inserted into nuclear reactors.

As we have sought to demonstrate the standards of production and the quality of the MOX fuel produced by Belgonucleaire is open to question. With comparatively limited experience in BWR MOX manufacture, an inferior technology in terms of homogeneity relative to BNFL, as well as a limited production capacity, non-fully automated production with a direct effect on worker exposure, there are sufficient factors to warrant a high standard of QC inspection. Instead it appears that Belgonucleaire apply a weaker QC than that of BNFL.

We have compiled for the first time and from various sources the parameters of QC applied during the production of MOX fuel in BNFL's MDF plant for Kansai Electric's Takahama unit 4, and compared them where possible with those QC checks used during production at Belgonucleaire's P0 for TEPCO's Fukushima-1-3 and Kashiwazaki-kariwa-3. As detailed in Table 2 for important areas of QC, Belgonucleaire conducts significantly less QC checks than does BNFL.

In particular, the number of plutonium enrichment tests conducted by Belgonucleaire for Fukushima MOX fuel is only 4% of that conducted by BNFL(1:43,000 at P0 compared with 1:1750 for BNFL). For impurities, such as carbon and nitrogen, again Belgonucleaire/Fukushima tests 22.5% of BNFL's (1:43,000 at PO compared with 1:9,700 at BNFL)

As for visual inspection for appearance of the pellets, Belgonucleaire/Fukushima inspects 46% of those conducted by BNFL (1:26 compared with 1:12). This also is an important factor when considering worker dose rates, in terms of a potential motivating factor for workers (and management) to minimize exposure through inadequate checking.

Even testing for homogeneity, BNFL conducts a greater number of inspections than Belgonucleaire, even though the evidence consistently demonstrates that the latter's fuel is less

homogeneous with greater pu- hot spots. Though as we have detailed the total checks and method of alpha-radiography used by both companies is inadequate, the fact that Belgonucleaire conducts fewer tests, 72% of BNFL's (1:13,500 compared with 1:9,700), indicates to us a complacency and disregard for the quality of their MOX fuel. Taking into account reactor safety aspects of inhomogeneous MOX fuel this is even less understandable. Given the fact that homogeneity tests are labor intensive, the pressure on Belgonucleaire to meet production targets is an additional likely factor in setting their QC standard so low.

The sampling procedure for pellet diameter in which Belgonucleaire workers are supposed to randomly select one pellet out of 150, then measure three points on the pellet, has we understand, been at the center of the efforts of Tokyo plaintiffs to secure an injunction against TEPCO's MOX plans. From a quality control procedural basis we find one of the most intriguing aspects of this case the fact that Belgonucleaire seems to have adapted an international QC standard MIL-STD-105D, even though, according to MITI, the original QC plan did not specify such an adaptation. Specifically, it has been reported in the Japanese Diet, that,

"As for MITI, we have heard from Tokyo Electric, that in the quality control plan it states that for each blender 32 MOX pellets should be randomly sampled, but at Belgonucleaire, in fact more than 32 pellets were randomly sampled."[18]

Although there was a pre-agreement to use the MIL standard, following further questioning in the Diet, it was confirmed by MITI, that,

"...we hear from Tokyo Electric that the number of pellets to be randomly sampled was decided by Belgonucleaire, but as for the criteria we are not aware."[19]

This appears to us to be a strange way for QC to be agreed particularly in light of what we now know occurred at the BNFL MOX Demonstration Facility. TEPCO and MITI it appears are relying on assurances from Belgonucleaire that such an adaptation of an international QC standard is nothing other than normal. As the plaintiffs in the case correctly surmise, there seems to have been no consideration of the increased options open to Belgonucleaire to manipulate data as a result of a change in the number of pellets sampled. It will be remembered that less than 12 months ago it became known that BNFL workers were not following the QC manual agreed by Kansai Electric. There remain serious questions as to why TEPCO originally cited the MIL standard and then changed its explanation that sampling was based upon an adaptation of MIL.

We are also concerned by the method of data recording by the QC inspector that has been disclosed by TEPCO. Again the plaintiffs in the case against TEPCO go into considerable detail on this point. We would agree with their analysis that there is a flaw in Belgnucleaire's procedure. During the random sampling procedure the inspector places the selected pellet in the measuring device (via the glove box) at which point the diameter measurement is automatically flashed on to the QC monitor (it is also pointed out that the inspector has the option to revolve the pellet 90 degrees to find a diameter measurement in specification). Another inspector assesses the data as to whether the pellet passes or fails. It is this inspector who has the

18 see, MITI response to questions in Japanese Lower House from Mizuho Fukushima, July 18, 2000.

19 Ibid.

opportunity to be selective in data entry. A foot pedal is required to be depressed to enter the diameter data onto a database. By not pressing the foot pedal the QC inspector can manipulate the QC results of the MOX fuel.

Collusion between management, QC workers and inspectors at the BNFL MDF was a key factor in the falsification of QC data for Kansai Electric. It seems entirely feasible for this to be a possibility in the Belgonucleaire case. A strong incentive on behalf of Belgonucleaire to not fail fuel has been highlighted by the plaintiffs. This points to the 0/1 failure QC, in which a failure of one out of 32 sampled per lot fails leads to the rejeciton of the entire 7000 pellet.[20] This relates also to the commercial pressure on Belgonucleaire to not reduce production output at a facility working beyond its nominal capacity.

TEPCO's argument that because there are two inspectors involved there is no possibility of date manipulation is not convincing in of itself, when it is considered that in the BNFL/Kansai falsification, inspectors worked in pairs one for measuring one for entering the data. Kansai Electric which had its own staff overseeing QC at the Sellafield site during MOX production, certainly if asked 18 months ago would have defended the QC procedure of BNFL. Indeed TEPCO stated in their February report,

"The diameter data measurement values are transferred directly to the computer, and there is no hand imput by inspectors. Therefore there is no possibility for inspectors to falsify data[21]

Not until July was this assurance contradicted by MITI,

"As for MITI, we have heard from Tokyo Electric that at Belgonucleaire, as you have pointed out, there is no mechanical system installed to prevent falsification of pellet measurement by altering the position of the pellet." [22]
Even after the MITI statement to the Diet, TEPCO have continued to insist that data manipulation was not possible.

In August, Takuya Hattori, General Manager of Nuclear Power Programs Department of TEPCO stated,

"In December, when the second falsification problem occurred (at BNFL), TEPCO sent employees to Europe three times, with a maximum of eight persons per visit, to reconfirm the data. We especially confirmed the management of the company's quality control system. In addition, we confirmed that there was no way that a person could intervene and falsify the data on the pellets outer diameter measurement on purpose, that there was no unnatural aspects and nothing had been added to the data received. Since we had made a confirmation once last September, we essentially conducted a reconfirmation in December." [23]

TEPCO appears to be following the same defensive, complacent and ultimately flawed approach as Kansai Electric (and MITI) followed one year ago. It appears to us that TEPCO and MITI have learnt little from the BNFL/Kansai Electric, or that they do not wish to. Citing the earlier September 1999 confirmation as evidence is almost entirely irrelevant as they were certainly not

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[20] see, Initial Statement by plaintiffs, p.19, submitted to the Fukushima District Court, August 9th 2000.

[21] see, TEPCO opcit, February, 2000.

[22] Opcit, MITI to Fukushima, July 18th, as cited in plaintiffs evidence, statement of Dr Koyama, August 9th, 2000.

[23] Plutonium, issue 29, 2000.

aware of even a fraction of the details that were to emerge over the following months from the BNFL MOX scandal. Of course it was in TEPCO's interest to re-confirm an earlier inspection otherwise it would expose the flaws in the earlier inspection.

As recently as December 13th, 2000, a MITI senior official admitted that the data so far released by Belgonucleaire in the form of histograms showing the pellet diameter data, could conceal data manipulation (which we believe could include pellets lots that were passed rather than being failed) due to the fact that the histograms so far released by Belgonucleaire/TEPCO are of intervals of 4 microns not the one micron data available to TEPCO.[24] Despite this, MITI have accepted TEPCO`s assurances that nothing is wrong. This is in contrast however to other customers of Belgonucleaire which together with their regulators continue to investigate QC at Belgonucleaire. We understand that audits of Belgonucleaire QC and production have been undertaken by the company's largest overseas client, Siemens.[25] These are now part of an on-going investigation by the German government into quality control and MOX safety which is due to conclude within the next few months.

AVI - NEITHER THIRD PARTY, INDEPENDENT OR RELIABLE

This section questions the independence of the verification agency used by TEPCO to confirm QC at Belogonucleaire and the thoroughness of the investigation conducted by the above and MITI.

TEPCO and MITI have issued assurances that the audit conducted by the "third-party" agency AVI of Belgium reconfirmed that QC procedures had been correctly followed at Belgonucleaire. We find this unconvincing. It is inaccurate to describe AVI as an 'independent third party'. AVI was established by the Belgian national inspection agency AVN. AVN in turn was formed by the Belgian research center SCK/CEN, which owns 50% of Belgonucleaire. SCK/CEN also has a contract for the inspection of enrichment and we believe homogeneity QC data of MOX fuel pellets for Belgonucleaire, including for TEPCO MOX fuel. In addition, we note that the TEPCO/AVI/JNF reconfirmation audit was conducted during January 2000. The report on this was authorized on February 23, 2000. This was only five days after the release of the Nuclear Installations Inspectorate, (NII) report on BNFL MOX falsification. With the AVI audit itself having been carried out prior to the issuing of the NII report, and the AVI report only being issued five days after the NII report, it is obvious that AVI was not able to utilize the information and analysis compiled by the NII on BNFL. It should be noted that the NII were not able to report on the full extent of falsification nor the motives for falsification. This was despite an investigation that began in September 1999. By comparison, AVI spent a minimal amount of time at Belgonucleaire merely verifying that the QC applied was consistent with the manuals.

24 Deputy Director, Nuclear Power Safety Administration, Public Utilities Department, Agency of Natural Resources and Energy, (ANRE), MITI, December 13th 2000.

25 See, for example the working group established by the German Environment Ministry that is considering MOX QC issues at European fabrication plants, including Belgonucleaire, and their implications for reactor safety., It is due to report to the government within the following months.

If AVI's superficial approach had been followed by the NII or Kansai Electric at BNFL, they would not have detected the extent of pellet diameter falsification of QC data by BNFL, and their investigation was hardly robust.[26]

The inadequacies of TEPCO's, MITI's, and AVI's investigation into the potential for violation of QC procedures by Belgonucleaire in areas other than pellet diameter are clear to us. Whereas it is generally perceived that the BNFL falsification related solely to pellet diameter, the reality was that data related to enrichment, density, and nitrogen content have been confirmed as falsified for MOX fuel produced for German and Swiss clients. These additional falsifications were only confirmed following the release of original QC data, including certificates, as well as further audit and investigations by German, and Swiss regulatory agencies and the fuel supplier Siemens. Without the release of such data from Belgonucleaire on the MOX fuel produced for TEPCO, we have no confidence that such types of falsification did not occur at P0, Dessel.

NEW COGEMA/FRAMATOME QC FAILURE

This section highlights a new, and yet to be fully understood, QC failure at a nuclear fuel cladding tube manufacturing plant in France, which has led to fuel cladding tubes that had not been correctly checked being incorporated into both uranium and MOX fuel.

The failures of European nuclear fuel manufacturing quality control have recently been exposed again on December 14th. This concerns the production of zirconium fuel cladding tubes at the Compagnie Europeenne de Zirconium (CEZUS), plant located in Paimboeuf, France, a subsidiary of Cogema and Framatome. As detailed in a report from the independent research agency, WISE-Paris[27], for 18 months, between August 1998 and February 2000, an utra-sonic scanner failed to inspect the first third of the first fuel cladding tube of each lot. All tubes are to be scanned in entirety during the principal QC check. Although the fault was discovered in February of this year, management of the plant failed to communicate the problem, to both customers and French regulators.

As WISE-Paris report, it was only with the failure of fuel cladding in a French reactor in August of this year, leading to a rise in radioactivity in the primary coolant, that an investigation by Framatome uncovered the problem at one of its plants. It was a further three months before the French nuclear safety regulator, DSIN, was informed, even though fuel cladding failure relates directly to the safety of fuel in reactors.

There are a number of important factors to do with this case that should give further cause for concern over the quality of the Fukushima-I-3 and Kashiwazaki-kariwa-3 MOX fuel, as well as the future production of MOX fuel for Japanese utilities in Europe.

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[26] see, Critique of NII report on British Nuclear Fuels MOX fuel quality control, April 11th, 2000, S. Burnie/A.M. Smith, Greenpeace International/Green Action.

[27] 'The CEZUS Affair: A flaw in the quality control of nuclear fuel', version 1, 6th December, X. Coeytaux/Y. Marignac/E.Rouy/M. Schneider, WISE-Paris.

The fuel cladding tubes that were manufactured by CEZUS have been supplied to nuclear fuel manufacturing plants throughout Europe. According to DSIN on December 6th, these include Belgonucleaire's and FBFC's plants at Dessel, both for MOX fuel and uranium fuel. The Melox plant and the Cadarache facility producing MOX fuel for Cogema also received fuel cladding tubes from CEZUS.

Forty-five percent of the world's zirconium alloy used by the nuclear industry, including for other purposes than tube manufacture, is supplied by CEZUS. Unlike Belgonucleaire which manufactures a small fraction of the total nuclear fuel in use, CEZUS supplies to many tens of reactors around the world.

During the same period of manufacture and delivery of the fuel cladding tubes to these plants, August 1998-February 2000, MOX fuel for both Kansai Electric and Tokyo Electric was being produced at Belgonucleaire PO and Melox. WISE-Paris cite assistant director of DSIN as not being able to exclude the possibility that MOX fuel manufactured for Japanese clients at the Melox plant could contain the 'incriminated tubes'.[28] It has subsequently been confirmed in Japan, that neither the Fukushima or Kashiwazaki Mox fuel contains zirconium tubes produced by CEZUS. The tubes for Japanese MOX fuel produced at Belgonucleaire is manufactured in Japan by Sumitomo. This is due to both concerns within the Japanese nuclear industry over QC at European fuel plants and the commercial arrangements in Japan that require purchase of Japanese produced nuclear equipment and matrerials. Nonetheless, it should be no comfort to TEPCO, or any other Japanese utility, that QC at French and Belgian nuclear fuel industry has been exposed as dangerously flawed. The issues of production standards, QC failure and transparency within the European nuclear fuel industry remains of central concern.

The fact that it has been confirmed that "some batches of tubes not yet used, in particular in the Melox MOX production unit, have been withdrawn from the production line raises more questions than it answers. How many fuel cladding tubes have already been incorporated[29] into MOX fuel manufactured by Cogema ? Further what guarantees can Cogema give that MOX fuel manufactured in early 2000 for Kansai Electric at Melox, and fuel currently being produced for TEPCO is not effected by this affair?

The regulators in both France and Belgium, as well as in the client states, including, Germany, the United States, China and Spain, where the fuel produced during the QC problem period has been delivered, will have to conduct a thorough investigations into this affair.

CEZUS at the start of its QC failure in 1998 was owned 51% by Framatome and 49% by the Cogema group. During 1999 Framatome became the sole shareholder. The Fukushima-I-3 MOX final assembly was undertaken at the 5M plant operated by FBFC, like CEZUS, owned 51/49 by Framatome and Cogema. The TEPCO MOX fuel contracts for Fukushima-I-3 and Kashiwazaki-kariwa-3 were signed with the COMMOX group, the largest party of which is Cogema. The same companies directly involved in this latest nuclear fuel scandal are those which produced MOX fuel for TEPCO (and Kansai Electric).

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[28] Ibid, WISE-Paris communication with DSIN Director, Philippe Saint-Raymond, December 6th.

[29] Ibid.

Although it took CEZUS management 18 months to detect this problem, why did both Cogema and Belgonucleaire also not detect the QC failure for fuel pins that they were using in their fuel manufacturing plant, given that they would have specified QC procedures with the company, and have access to the data ? It is as much their QC failure as that of CEZUS. The QC failure, and the fact that CEZUS with-held the fact of the failure from clients and the regulators demonstrates the willingness of nuclear fuel companies to avoid public scrutiny. As WISE-Paris points out, the discovery subsequent non-disclosure of the QC failure coincided with the high point of the BNFL/Kansai Electric QC scandal.

In an earlier report by the authors we suggested that the nuclear fuel manufacturing industry had never been exposed to public scrutiny as it had been during the BNFL affair, and that standards of production and quality control were fundamentally flawed. The CEZUS affair as revealed by WISE-Paris, underscores this earlier conclusion.

REGULATORY OVERSIGHT IN MOX FUEL STANDARDS

This section discusses the fact that there are no international agreed standards for MOX fuel, and that the producers and clients agree to standards that suit commercial rather than nuclear safety interests. It is pointed out that there are no sanctions imposed on MOX producers for violating QC procedures, highlighted by the continued ISO accreditation of the discredited BNFL MOX plant.

The BNFL/Kansai Electric case exposed to public scrutiny for the first time many important issues to do with the standards of manufacture of MOX fuel. One of the most important was the lack of domestic and international regulatory control over MOX fuel standards.

Belgonucleaire and TEPCO have emphasized in the past 12 months that the P0 MOX plant that produced the fuel for Fukushima-I-3 (and Kashiwazaki-kariwa-3), has been produced in a facility with Quality Assurance (QA) certification. Specifically, P0 has International Standards Organization (ISO) 9002 and 14001 classification. However it is worth pointing out that along with Belgonucleaire's having such certification so to does BNFL's MDF plant that produced the MOX fuel for Kansai Electric's Takahama-4. Cogema's Melox also has ISO accreditation, as does the CEZUS zirconium fuel cladding tube production plant.

The ISO states that one of the principles followed in developing international standards is "consensus". It says, "The views of all interests are taken into account: manufacturers, vendors and users, consumer groups, testing laboratories, governments, engineering professions and research organizations.[30] In everyday life certification of a product to a given quality assurance standard, is an indication that it can be expected to perform reliably. The World Standards Services Network states,

"For the user [certification] provides assurance that the product purchased meets defined characteristics or that an organisation's processes meet specified requirements. Certain product certification marks may represent an

[30] see, www.iso.net

assurance of safety and quality".[31] There is no doubt that badly made nuclear fuel can affect the safety of a nuclear reactor. The UK's Nuclear Installations Inspectorate (NII) states,

"The quality of nuclear fuel loaded into a reactor can potentially affect safety as well as the performance of the reactor. We are concerned only with safety and expect the purchaser to require and confirm appropriate quality assurance arrangements to ensure that only fuel of the correct standard is applied." [32]

The UK Environment Agency states,

"In manufacturing MOX fuel, BNFL is required to meet the customer's specification for fuel composition and design. The fuel specification is fundamental to the safety case for the operation of a nuclear reactor. It is for the customer to satisfy the regulatory authorities in its own country that the fuel is safe to use in the customer's reactors. The Agency takes the view that the regulatory authorities in countries to which BNFL might return plutonium in the form of MOX fuel would not permit such fuel to be loaded in reactors unless they were satisfied that the safety risks associated with its use were low." [33]

It seems reasonable to expect that nuclear regulators world-wide should ensure that operators of their licensed nuclear sites only buy fuel that has been certified to strict quality assurance standards. One might expect that even greater care will be taken in the manufacture of plutonium fuel (MOX) than with ordinary uranium fuel, because of the increased complexity and greater safety risks. However, this is not the case.

The regulators in Belgium, France, and Japan have not set any product standards for MOX fuel. In Japan, for example, the law is vague about requirements for MOX fuel. It states that plutonium uniformity *"must not be a hindrance for practical use"* and that deviations in measurements and consistency *"must not be remarkably large".* [34] However, these vague requirements do expose the complacency of the safety authorities in overseeing the quality of plutonium MOX pellets. There is no way to judge how badly made the pellets would have to be before Japanese regulators would consider them unsafe for use in a reactor.

There is also no international product standard for MOX fuel pellets. In fact the technical working group of the International Organisation for Standards responsible for "Measurement methods for chemical and physical characterization of MOX pellets" was only set up in March 1998. So far it has published no standards at all.[35] This working group is run by BNFL, *"...on behalf of..." the British Standards Institute (BSI)*[36]

There is one ISO standard on the plutonium dioxide powder to be used for making MOX fuel pellets, but it is limited only to "Guidelines to help in the definition of a product specification".

31 see, www.wssn.net

32 see, Letter from UK Nuclear Safety Directorate to Greenpeace UK, 15th March 2000.

33 see, UK Environment Agency (1998) document containing the Agency's Proposed Decision on the Justification for the Plutonium Commissioning and Full Operation of the Mixed Oxide Fuel Plant, BNFL, PLC, Sellafield, October 1998, para. A4.149.

34 Ministerial ordinance about technical standards concerning power generating nuclear fuel. Article 5 (4),(5) (Ministry of International Trade and Industry Ordinance, June 15th 1965)

35 see, ISO to Greenpeace, 23rd February 2000.

36 see, BSI to Greenpeace, 8th February 2000.

The Standard states *"As it cannot be considered a standard product, the plutonium consequently cannot form the subject of general supply specifications, as is the case for uranium".* [37]

This means that the regulators have in effect left it up to Belgonucleaire, BNFL, Cogema and its customers to agree the specifications for MOX fuel amongst themselves. [38] This decision is a major regulatory failure. This failure has led to no one taking responsibility for the threat to nuclear safety that could be posed by badly manufactured fuel. This is not perhaps surprising given the monopolistic nature of the nuclear fuel industry.

MOX manufacture is not widespread, and therefore Japanese utilities, if they are to continue their 'pluthermal program', have to rely upon two suppliers - BNFL and COMMOX. It is not in the interests of Japanese utilities interests to question too severely the safety or reliability of its only MOX fuel suppliers, when they have no alternative supplier.

It was only after the final admission by BNFL in December last year that it had falsified QC data that the scale of the MOX production problem emerged. It was also only after this that Kansai Electric announced that it would not be using the BNFL MOX fuel. There are striking similarities with the Belgonucleaire/TEPCO case.

On March 1st 2000, Kansai Electric released a report on the MOX falsification scandal in Japan. The report states that Mitsubishi Heavy Industries (MHI) carried out an inspection of BNFL's MDF in 1995. Kansai Electric's report *states "[MHI confirmed that [BNFL's] ability to fabricate pellets with a low spread of diameters was insufficient, and we received a report about this, but we did not take sufficient steps to have BNFL improve their production ability".* [39] In other words, BNFL's customer knew that there was a fundamental production problem with the plant, yet did not require this problem to be solved. The regulators in Japan, who are ultimately responsible for checking the safety of Kansai Electric's reactors, either did not know or did not care. The parallels with where we currently are with the Belgonucleaire/ TEPCO MOX are obvious.

Once a product standard has been set - even if it is only agreed between the fuel manufacturer and its customers - someone has to check that the standard is being met. According to the British Standards Institute (BSI) a quality management system is *"...a common-sense, well documented business system; applicable to all business sectors, which helps to ensure consistency and improvement of working practices, including the products or services produced."* [40]

The MOX Demonstration Facility (MDF) at BNFL's Sellafield site has been independently certified to the international management standard ISO 9002 by Lloyd's Register Quality Assurance (LRQA). LRQA states that companies which undergo certification achieve benefits to their business which include,"improved efficiency and less production waste; improvement in

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[37] see, ISO 13463: 1999, "Nuclear-grade plutonium powder for fabrication of light water reactor MOX fuel - Guidelines to help in the definition of a product specification."

[38] see, for example NII (2000a), "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", 18th February 2000.

[39] see, KEPCO 2000, An Investigation into the Problem of MOX Fuel Fabricated at BNFL (Interim Report), 1 March 2000, Section 3.4.2, translated and summarised by Green Action.

[40] see, www.bsi.org.uk, "ISO 9000 - Questions and Answers."

system control; increased customer satisfaction; increased market share; reduction in customer audits."[41]

The ISO states that, *"the objective is to give the organization's management and its customers confidence that the organization is in control of the way it does things.*[42] There is no doubt that by falsifying quality assurance data on MOX fuel sent to Japan and Germany, BNFL has lost the confidence of its customers. In a memo to BNFL's Chairman, Hugh Collum, BNFL's communications advisors state,

"BNFL is in a crisis - a crisis of confidence affecting every aspect of the company... This crisis of confidence is shared by most, if not all, the company's stakeholders. Key customers, the DTI and many politicians, have lost confidence with senior management. Internally, employees at Sellafield have lost confidence in corporate management." [43]

Yet, unbelievably, BNFL still retains accreditation to the quality management standard ISO9002 on the MDF, as well as for other plants at Sellafield.

BNFL's MOX Demonstration Facility was awarded ISO9002 in 1998[44] although the first falsification of quality assurance data in the MDF noted by the NII was in 1996.[45] Falsification of quality assurance on Japanese MOX fuel occurred whilst the MDF was accredited to this international quality management standard, yet appears not to have been detected by LRQA during its 6 monthly visits. Even after the public discovery in 1999 of the falsification of QC pellet diameter data, and when BNFL's claims that fuel sent to Japan had not been affected were proved false, LRQA did not remove the certificate.

The award or retention of ISO9002 by a company, whether it be BNFL, Belgonucleaire or Cogema clearly should not provide any confidence at all to either its customers, regulators or the public that procedures are being followed, or that public statements are correct. This should come as no surprise as ISO standards are not legally enforceable, and in addition have no sanctions attached if violated.

The nuclear industry worldwide and its regulators have never bothered to agree international quality assurance standards for plutonium fuel. Belgonucleaire, Cogema and BNFL customers have accepted weak standards as well as failing to notice when things go wrong. Regulators have turned a blind eye, even when presented with the evidence, or argued that the issue is not their responsibility. Quality Assurance bodies have been secretive and viewed their role as acting solely in the interests of the MOX producers and customers. Significantly recent reports suggest that the non-nuclear industrial community in Japan at least are increasingly questioning ISO standards, in particular the 9000 series, Toyota has reported earlier this year that they will not be using ISO 9000. The following description of ISO 9000 could have been drafted specifically to describe QC in the MOX industry,

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41 see, www.lrqa.com "Services"

42 see, www.iso.ch, "Publicizing your certification".

43 see, Bell Pottinger (2000), Communications Recommendations, Reputation Recovery (draft 2), 22 February 2000.

44 see, BNFL(1998), Annual Report and Accounts.

45 see, NII(2000a), para 103.

"It makes people do things that makes them worse and stops them doing things that would make them better."[46]

Although the UK's Nuclear Installations Inspectorate (NII), went out of its way to assure Kansai Electric and MITI, that the fuel was safe to use, they had no practical experience to issue such an assurance. In fact the NII is explicitly exempted from assuring the safety of nuclear fuel intended for overseas customers. In the case of the MOX fuel produced for Fukushima (and Kashiwazaki-kariwa) by Belgonucleaire, again it is neither the Belgian regulator, nor Belgonucleaire, that is required to ensure the safety of the fuel. The Belgium nuclear research center, CEN/SEK confirmed as much in a March report,

"The fuel producer is not responsible for an accurate safety analysis of the reactor core or for the way in which the fuel is being used. It is the users and fuel vendor's role to check if the fuel actually meets the specifications and that it is used under the prescribed conditions. The accredited organization only carries out inspections regarding safety."[47]

As SCK make clear, it is the manufacturer, in this case Belgonucleaire, to ensure that the fuel meets the criteria agreed with the client. The specifications required to meet the particular reactor core design and how the fuel will be used, *are "imposed by the fuel vendor on the manufacturer".*[48] In this case, TEPCO, through a Toshiba contract with Belgonucleaire. This of course would have been the same process BNFL followed when agreeing with Mitsubishi Heavy Metal (HMI) and Kansai Electric prior to the manufacturer of MOX fuel for Takahama units 3 and 4. Amongst the many things the BNFL case demonstrated was that the fuel manufacturer, if it so wishes, has every opportunity to violate agreed criteria 'imposed' by the fuel vendor. What was an option utilized by BNFL, certainly was, and remains, an option for Belgonucleaire (and Cogema). Given the reduced frequency of inspections at BN and the fact that at best the QC checks on pellet diameter can be described as only semi-automated, the opportunity for data manipulation could even be said to be greater at BN than at BNFL.

COMMERCIAL SENSITIVITY AND MOX QC DATA

This section points out that MOX fuel manufacture is not a highly competitive market, being as there are only two commercial producers, BNFL and the COMMOX group (Belgonucleaire and Cogema). Consequently, citing commercial sensitivity as justification for with-holding QC data is not credible.

During the last 12 months it has been claimed by TEPCO, Belgonucleaire, Cogema, and MITI, that to release quality control from the production of MOX fuel would be damaging to the commercial interests of Belgonucleaire and the wider COMMOX group. In one sense they are correct in that once public, it will become clear that inadequate production and QC standards exposed at BNFL extend also to the COMMOX group. This issue aside, the argument that QC data release could assist competitors in their production as has been stated by a Belgonucleaire official is spurious. A basic overview of the MOX market will highlight this.

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46 see, The quality you can't feel, The Observer, J. Sneddon, 19th November 2000, citing the book, 'The case against ISO 9000', Oak Tree Press.

47 see, opcit, CEN/SEK report "Review of the report 'Fundamental Deficiencies in the Quality Control of Mixed-Oxide Nuclear Fuel", Reactor Safety KvdM/PV/MV - 31 RVSB000 800/00-01 Mol, March 20th 2000.

48 (ibid, p2.).

There are two commercial MOX manufacturers in Europe BNFL and COMMOX. The latter is the commercial representative for Cogema and Belgonucleaire, which operate three MOX fuel facilities. As already detailed, BNFL use the SBR method of production. They have two facilities, MDF, and the yet to be opened Sellafield MOX Plant, SMP. This plant, costing over 500US$ million, has yet to secure contracts beyond 7% of its capacity. Both Cogema and Belgonucleaire have worked over the years to develop and refine the MIMAS technology. All three plants in France and Belgium use MIMAS.

The MOX fuel industry is not therefore comparable with the electronics or food industry. The particular data that has been called for release largely relates to the diameter of the pellets measured during the inspection and QC stages. Pellet data will show the accuracy of the production process as it relates to the size of the pellet. That is indeed important from a safety point to view.

However, Belgonucleaire's only other competitor, BNFL, has released all-pellet measurement and QC for MOX fuel produced at the MDF. The technology used in the MDF has been incorporated into the Sellafield MOX Plant. In addition, the new BNFL Chief Executive Norman Askew has stated that if the SMP opens, *"all QC data will be released publicly ...to assure public confidence."*[49]

In addition, in March 2000 a report was released by NUPEC, which, in over 150 pages of fine detail explains the process whereby MOX fuel pellets are measured for homogeneity and what the results for both BNFL and MIMAS/Belgonucleaire are in terms of plutonium hot-spots. The issue of homogeneity goes to the heart of the quality of the MOX production process. It is clear from the data contained in this report that Belgonucleaire, Cogema, and BNFL are prepared to have their most sensitive QC data released publicly.

From a commercial perspective, given the nature of the MOX fuel industry, there is no logic to the withholding of pellet diameter data for the Fukushima-I-3 and Kashiwazaki-kariwa-3 MOX fuel.

MOX FUEL AND NUCLEAR REACTOR SAFETY

This section provides a brief overview of the general safety issues related to MOX fuel, and then focuses on the specific issue of pellet diameter, cladding interaction and BWR reactor safety. We conclude that given the doubts over QC at Belgonucleaire, including the possibility of data manipulation, there are indeed serious safety risks associated with the loading of the 32 MOX fuel assemblies into Fukushima-I-3.

Reactor operators and MOX producers generally claim that burning MOX in light-water reactors designed to use ordinary uranium oxide fuel does not pose any additional safety problems. These claims are usually based on the fact that plutonium is produced continually during the operation of a reactor fuelled conventionally with uranium oxide and that some of this plutonium undergoes fission's, typically accounting for approximately one third of the total fission's. It is

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49 personal communication to author, October 12th 2000.

concluded that plutonium fission's in LWR's do not constitute a new problem. Such arguments are flawed. Many of the general and specific issues of MOX reactor safety consequences have been addressed in considerable detail in earlier evidence submitted to the Fukushima District Court, and we refer the reader to the important points made in these submissions.

In a typical uranium oxide fuel element, subjected to a burn up of 35,000 megawatt days/ton, the amount of plutonium accumulated in the fuel element while in the reactor will be about one per cent of the weight. In a typical new MOX fuel element, plutonium will account for five per cent or more.

To say the least there have been an inadequate number of safety studies for reactors containing MOX fuel. Moreover, those conducted by the nuclear industry, are virtually impossible to obtain. The nuclear industry keeps them secret, claiming commercial confidentiality.[50] When the industry claims that safety analyses have shown that the behavior of MOX fuel assemblies is very similar to that of uranium oxide assemblies, these analyses have not been subjected to objective independent assessment.

Two types of causes contribute to an increase in risk in reactors burning MOX compared to those reactors burning uranium oxide fuel. Firstly, the fact that MOX fuel pellets are constructed from two actinide oxides rather than one makes fabrication and quality control considerably more difficult for MOX compared with uranium oxide fuel. Secondly, differences in properties of plutonium and uranium in the core of a MOX-burning reactor alter the functioning of the reactor with adverse consequences for safety.

Compared with uranium oxide, plutonium oxide has a melting point which is more than 30 degrees Centigrade lower; it is less effective at conducting heat; and it releases a greater volume of gaseous fission products. These differences reduce the safety of reactors using MOX fuel. The properties, for example energy and number, of the neutrons produced during the fission process of MOX fuel, or neutronics, will reduce the effectiveness of control of the reactor. Also, neutron irradiation will do more damage to the materials used to construct the core and its surroundings. This over a period of time could have adverse consequences for reactor safety.

Reactivity coefficients of MOX fuel are more negative possibly causing variations in power output, which could result in a reduced margin for the shutdown of the reactor in an accident. These issues are likely to increase the speed with which an accident evolves and increase the severity of an accident. This factor is more important for BWR's, such as Fukushima-I-3 and Kashiwazaki-kariwa-3, than PWRs, because they experience higher energy releases during accidents, particularly reactivity insertion accidents.

Core physics determine that MOX fuel behaves significantly different from uranium oxide fuel in the following main ways:

[50] Requests by the authors to nuclear regulatory bodies seeking reactor safety studies made by the nuclear industry have consistently refused.

The probabilities (cross-sections) of nuclear fission's following the absorption of a neutron and the cross sections of the capture of a neutron without fission for plutonium isotope 239, 240 and 241 are very different from those of uranium-235, the uranium isotope involved in fission in the reactor. The plutonium-239 cross section, for example, is greater than that of uranium-235 in the thermal field.[51] Because of these differences in cross-sections, MOX fuel absorbs more neutrons of low energy so that the average energy of the neutrons in the core of the reactor is greater. There is a shift of the neutron spectrum towards the epithermal neutron field with energies in the range of 0.1-100 electron volts.[52] The boron in the reactor control rods is less able to absorb the more energetic neutrons thus the control of the reactor is less effective. For the same reason, boron introduced into the coolant of pressurized water- and boiling-water reactors in an emergency shutdown will be less effective. This reduction in the efficiency of control rods and borated coolant has an adverse effect on reactor safety.

The curves of the cross-sections of plutonium-240 show resonances for epithermal neutrons. This means that the negative reactivity required to go from full to zero power will be increased.[53]

This reactivity is compensated by control rods, so that the total neutron absorbing capacity of the control rods in the fuel assemblies must be greater than those used for a core fuelled only with uranium dioxide

MOX fuel, compared with uranium dioxide fuel produces fewer delayed neutrons.[54] The fraction of delayed neutrons for plutonium-239 (0.0021) is more than three times less than that for uranium-235 (0.0065). Thus the neutron flux in a core fuelled with MOX will tend to increase more quickly than one fuelled with uranium dioxide. This makes the control of a reactor fuelled with MOX more difficult than one fuelled with uranium dioxide.

Because of differences in neutronic behavior between uranium oxide and MOX fuel assemblies, there will be increases in neutron fluxes at interfaces in the reactor. Normally, an attempt is made to reduce this effect by using different plutonium contents in each MOX assembly. Nevertheless, some increase in peak thermal fluxes will occur at the hottest spots in the fuel rods, impairing operating flexibility.[55]

The release of fission gases in MOX fuel is greater than in UO2 fuel for a given burnup. Fission gas release may be greater in MIMAS MOX than in SBR MOX. One factor leading to a higher fission gas release may be the plutonium distribution in the MOX pellets. Helium is produced in greater quantity in MOX fuel than in UO2 fuel. The main contributor to helium production in MOX is cerium-242. The amount of helium produced depends burn-up as well as the amount of plutonium initially in the MOX. Xenon and Krypton are produced in quantities greater that the

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51 see, Graves, H. W. Jr., Nuclear Fuel Management: Chichester, John Wiley and Sons, 1979.

52 see, ibid. Grave et al.

53 see, Report of the International MOX Assessment, Comprehensive Social Impact Assessment of MOX Use in Light Water Reactors: J. Takagi, M. Schneider, F. Barnaby, I. Hokimoto, K. Hoskawa, C. Kamisawa, B. Nishio, A. Rossnagel, M. Sailer, Citizens' Nuclear Information Center, Tokyo, November 1997.

54 see, Vliet, J., Haas, D., Vanderborck, Y., Lippens, M., and Vandenberg, C., MIMAS MOX fuel fabrication and irradiation performance, paper presented to the International Seminar on MOX Fuel, Institute of Nuclear Engineers, Windermere, England, 4 June 1996.

55 Opcit, Grave et al.

amount of helium produced. The helium/xenon+krypton ratio is typically 0.07 at a burn-up of 40,000MWd/t, rising to 0.18 at 60,000MWD/t.[56]

In summary,

To summarize these, MOX reactor fuel has physical properties that are different from ordinary UO2 reactor fuel, affecting the thermal and mechanical performance of the fuel rods. The main effects are: reduction of the control rod and neutron absorber worth's because of the higher thermal absorption cross-sections of Pu relative to those of U, reducing the margin for shutting down the reactor;[57] MOX has greater fission cross-sections at higher neutron energies than UO2 fuel, resulting in the coolant void coefficient of reactivity being less negative for MOX than for UO2 fuel; the harder neutron energy spectrum in MOX fuel, and the consequent higher neutron energies, may increase the damage done to the pressure vessel of the reactor by neutron irradiation,[58] because the thermal conductivity of MOX, compared with UO2, is reduced, the energy stored in the fuel rods in a loss-of-coolant-accident is increased; higher temperatures also increase the release of fission gases from MOX fuel and increase the pressure in the rods; plutonium hot spots may affect the behaviour of MOX fuel[59] and the cladding of MOX rods during reactivity accidents, a problem that has not been resolved[60]); the different concentrations of fission products and actinides in MOX fuel may increase the severity of a reactor accident; the larger amounts of actinides in MOX fuel the decay heat of the fuel rods will be greater; the much larger amounts (by between 5 and 22 times) of actinides in MOX fuel may increase, by about one-third, the number of fatal cancers produced by a reactor accident. [61] Releases of up to 5 per cent of the actinide inventory of a PWR core may be released in severe accidents, compared to up to 10 per cent of the actinide inventory of a BWR core.

In the context of accidents in reactors fuelled with MOX, it should be noted that, although MOX ceramic melts at a temperature of about 1,800 degrees Centigrade, surface oxidation occurs at the much lower temperature of about 250 degrees Centigrade if the fuel is exposed to air. At relatively low temperatures, exposed MOX pellets produced respirable-sized particles following relatively short exposure periods. For example, 1.87 per cent of the initial mass was rendered respirable when MOX fuel was exposed at 430 degrees Centigrade for 15 minutes, compared to 0.01 per cent at 800 degrees Centigrade.[62] A particle with a diameter less than 3 microns can be inhaled into the human lung, with a resultant substantially increased public health risk of lung cancer due to the alpha radiation.

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56 see, Lippens, M., Maldague, Th., Basselier, J., Boulanger, D., and Mertens, L., Highlights of R&D Work Related to the Achievement of High Burnup with MOX Fuel in Commercial Reactors, IAEA/OECD-NEA International Symposium on MOX fuel cycle technologies for medium and long term deployment: experience, advances, trends, International Atomic Energy Agency, IAEA-SM-358/III, Vienna, 17-21 May 1999.

57 Opcit, IMA, Takagi et al

58 see, United States Nuclear Regulatory Commission, Mixed-Oxide Fuel Use in Commercial Light Water Reactors, Memorandum from Executive Director for Operations, United States Nuclear Regulatory Commission, Washington DC, April 14, 1999.

59 Willermoz, G., Bethoux, P., Bruna, G. B., Castelli, R. and Serant, D., Modelling of manufacturing fuel heterogeneities in a PWR via a stochastic - perturbative method, Prog. Nuc. Energy, Vol.33, pp. 265-278, 1998.

60 see, Grandjean C. and Lebuffe C., High Burnup Fuel Cladding Embrittlement under Loss-of-Coolant-Accident Conditions, Proceedings of the Topical Meeting on Safety of Operating Reactors, ANS Seattle, September 17-20, 1995.

61 see, Lyman, E. S., The Impact of the Use of Mixed-Oxide Fuel on the Potential for Severe Nuclear Plant Accidents in Japan, Nuclear Control Institute, Washington DC, October 1999.

62 see, Seehars, H., and Hochrainer, D., Durchfuhrung Experimenten zur Unterstutzung de Annahmen zur Freisetzung von Plutonium bei einem Flugzeugabsturz, Franhofer-Institute, SR 0205A, March 1982.

REACTOR SAFETY ISSUES SPECIFIC TO BELGONUCLEAIRE/FUKUSHIMA MOX FUEL

The manufacture of nuclear fuel must, as far as possible, provide high assurance that in the event of a severe nuclear accident the nuclear fuel remains intact and in a geometry that is conducive to heat removal until safety systems become available. If significant numbers of fuel failures occur early in the accident, fission products will be released and changes in fuel geometry may interfere with the flow of coolant through the core, "increasing the risk that fuel heat-up will continue until the irreversible core melting and quantitative fission product release occur."[63]

What the evidence shows so far is that Belgonucleaire has not provided convincing assurance that the Fukushima-1-3 MOX fuel has been produced to the highest standards, and that in the event of an accident it will remain intact. In fact research currently underway raises the possibility that the poor QC standards of MOX fuel produced at Belgonucleaire, including possible manipulation of QC data, will increase the potential for an accident to occur in the first place at Fukushima.

In new research to be published in early 2001, Dr Edwin S. Lyman, Scientific Director of the Nuclear Control Institute, the case is made that the implications for reactor safety are directly related to the problems of QC, and in particular the reliability of the pellet diameter data at the Belgonucleaire MOX plant.

The issue under investigation relates to BWR's such as Fukushima-1-3 where a transient that can initiate a nuclear accident known as a power oscillation "aniticipated transient without scram" (ATWS). Given the urgency of the current situation regarding plans by TEPCO to load MOX fuel into Fukushima-1-3, and the serious implications of Lyman's research, we highlight some of the issues he so far has addressed.

It is known that if there is a failure to successfully scram a reactor, the average core power and fuel temperature will rise until fuel cladding failures occur and fuel fragments are expelled, resulting in fuel-coolant interactions, steam explosions, pressure pulses and blockages of coolant flow. Hence the need to ensure the ability of the fuel to withstand the stresses induced by this type of accident.

Why this issue is so pertinent to the Belgonucleaire/TEPCO MOX fuel is that a relatively low-temperature mechanism that has the potential to cause BWR fuel cladding to fail during a power oscillation is known as pellet-clad mechanical interaction (PCMI). As Lyman notes,

"In unirradiated fuel, a gap on the order of 150 microns is present between the fuel pellet surface and the interior surface of the fuel cladding. During irradiation, the fuel pellet initially shrinks, but eventually begins to undergo thermal expansion, as well as swelling from the accumulation of fission product gases...As a result, the pellet-clad (P/C) gap first increases then decreases. If the gap eventually closes, the pellet and cladding come into hard contact. Further pellet expansion exerts tensile stress on the cladding (and the cladding exerts compressive stress on the pellet). PCMI can cause cracking of both the fuel and the cladding, ultimately inducing cladding failures if it is sufficiently severe."[64]

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63 see, 'The Importance of MOX Fuel Quality Control in Boiling-Water Reactors", research paper draft, in progress, Dr Edwin S. Lyman, Scientific Director, Nuclear Control Institute, Washington DC, December 14th.)
64 ibid.

Though PCMI is rarely a problem, a power oscillation could cause this rapid fuel temperature and pressure increases, which could accelerate pellet expansion and gap closure, inducing a PCMI. Brittle fracture of the cladding could also occur if there is insufficient time for the cladding to heat-up.

Why the current debate over the safety of MOX fuel for Fukushima-I-3 (and Kashiwazaki-3) is so pertinent is that it has until recently industry and the nuclear research community had considered that PCMI was not a significant problem for BWR's because cladding creepdown is lower and P/C gap correspondingly wider. This will as a result of recent Japanese government funded research have to be revised. Lyman, reports that experiments conducted by JAERI (Japan Atomic Energy Research Institute) Nuclear Safety Research Reactor (NSRR) have *"demonstrated this is not the case for high-burnup uranium fuel."*[65]

TEPCO will be aware of this research, not least because the uranium fuel tested by JAERI came from the Fukushima-II-2 reactor. The experiments led to the severe failure of the fuel when exposed to conditions simulating a BWR power transient in the NSRR.[66]

During the experiment, 100% of the fuel was finely fragmented and dispersed into the reactor coolant. As reported by JAERI, the fuel was reduced to a powder. As Lyman notes, "if this had occurred in a power reactor, it would have caused severe pressure pulses, distorting the core geometry and affecting the ability to operate the reactor control system."[67]

MOX fuel use in Fukushima-I-3 (and Kashiwazaki-3) will increase the risk of a severe core melt accident caused by power oscillation. Lyman summarizes the principal reasons:

- the use of MOX will increase the severity of a power oscillation transient - due to a more negative void coefficient and the smaller size of delayed neutron fraction caused by MOX loading, this will increase the frequency and amplitude of the power oscillations; in addition the thermal conductivity of MOX fuel is lower than uranium fuel, leading to increased fuel temperature and power increases reducing the time that operators will have to intervene;

- the performance of MOX fuel is inferior to uranium fuel of the same burnup, in such areas as fuel swelling and fission gas release (CABRI test results in France clearly demonstrate this). There is no equivalent data for BWR MOX. Lyman notes that JAERI tests with BWR MOX fuel at the NSRR in Japan have been on fuel with a burnup of 20MWd/t, half that which TEPCO have been licensed to operate at Fukushima-I-3. It is noted that in two of the JAERI tests the pellet clad gap closed and PCMI occurred, causing significant residual strain on the cladding. The P/C gap for the ATR MOX fuel had shrunk by around 50%, or 75 microns during the base irradiation.[68]

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65 see, T Fukeda et al, JAERI, "High Burnup BWR Fuel Response to Reactivity Transients and A Comparison with PWR Fuel Response," Transactions of the 28th Water Reactor Safety Information Meeting, Bethseda, MD: U.S. Nuclear Regulatory Commission, October 23-25, 2000.
66 Ibid.
67 see, W. Yuen and T. Theofanous, "A Scoping CFD Evaluation of RIA Consequences," U.S. Nuclear Regulatory Commission, undated, (on the NRC website) as cited in Lyman, December 14th.
68 see, opcit, T. Fukeda et al, "JAERI Research on Fuel Behaviour During Accident Conditions," as cited by Lyman.

Significantly, as Lyman points out, BWR uranium fuel at far higher burn-up (45GWd/t) and with similar initial P/C gaps and cladding material to the ATR MOX fuel did not exhibit P/C gap closure or significant cladding strain. This demonstrates further that the effects seen in very high burnup uranium fuel, above 50GWd/t, occur at much lower burnups for MOX fuel. TEPCO plans to operate the Fukushima-1-3 at a an assembly maximum burn-up of 40,000MWd/t. This should be compared with the maximum fuel assembly exposure for the only BWR with a large core load of MOX fuel, Gundremmingen-B in Germany, which up to 1998 was 32,000MWd/t. No reactor operator in the world has experience of operating a BWR with a large MOX core at the burn-up levels planned by TEPCO, again raising serious questions over the safety culture of the utility.

In conclusion, Lyman notes that,

"... the vulnerability of BWR fuel to PCMI during oscillation-type transients appears to be quite sensitive to the initial P/C (pellet-clad) gap of the fuel, very tight control of the P/C gap during fuel fabrication, as well as thorough understanding of its evolution during fuel irradiation, are essential for providing high assurances in safety of high burnup BWR fuel during transients...An uncertainty of 20 microns in the pellet diameter, which is the current tolerance for the MOX fuel destined for Fukushima, appears to be highly significant with regard to P/C gap evolution, and therefore unacceptably large."[69]

As stated earlier the tolerance agreed between TEPCO and Belgonucleaire for pellet diameter of +/-20 microns is twice that agreed between Kansai Electric and BNFL for Takahama MOX fuel, +/-10 microns. The implications of this latest research are to make even stronger the case that the issue of QC of MOX fuel during production of fuel at Belgonucleaire for Fukushima, including inspections for pellet diameter, is of fundamental importance to reactor safety.

This unfortunately is not the view of TEPCO, the Japanese nuclear safety regulators at MITI, or Belgonucleaire. Despite the mounting evidence, including from their own research institutes, those agencies responsible for nuclear safety in Japan continue to deny that there are significant behavioral differences between uranium and MOX fuel with serious implications for reactor safety. Their approach is to deny the basic laws of physics and hope that nothing goes wrong. That unfortunately was the attitude that led directly to the JCO Tokai-mura criticality accident a little over twelve months ago. It appears that little has been learned from that accident. In assessing the risks of MOX fuel a number of years ago, a nuclear engineer, now a member of the German government nuclear safety division observed that,

"In critical situations, the requirements of which transcend normal levels - in particular reactivity incidents and transients - even small reductions of safety margins in control can lead to serious problems and accidents. The danger that incidents for which the plant is designed develop into major accidents is thus increased by the use of MOX."[70]

The decision to proceed with the loading of MOX fuel in any reactor in Japan is one we believe that will increase the risks and consequences of a serious nuclear accident. However, for TEPCO to proceed with the loading of 32 MOX assemblies currently in storage at the Fukushima-1-3

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[69] Opcit, Lyman.

[70] See, Dr Michael Sailer, member of the German government's Commission for Nuclear Safety, including member of the working group on plutonium and spent fuel management, see, The MOX Industry, IPPNW, 1994.

reactor, given the obvious weaknesses in both the production process and application of QC, as well as the justified suspicions over QC data manipulation at the Belgonucleaire PO plant, is inexplicable and irresponsible.

CONCLUSION

The safety of conventional thermal nuclear reactors fuelled by MOX is seriously compromised by two important considerations: difficulties in the fabrication and quality control of MOX fuel pellets and differences in the behavior of plutonium and uranium in the reactor.

Of great importance is the homogeneity and pellet-clad gap of MOX fuel. The cost of properly checking for inhomogenieties in the distribution of plutonium in a fuel pellet, by, for example, alpha-autoradiography, would be large, from a commercial point of view prohibitively so. Recent research indicates a very serious problem related to pellet-clad gap mechanical interaction with potentially severe consequences for reactor safety, again requiring precise and reliable fuel manufacturing techniques.This is compounded by the current poor economics of the MOX industry. Available estimates suggest that MOX supply will be about two times greater than MOX demand up to the year 2015. The pressure to reduce costs in such a competitive market inevitably has impacts on the extent, and therefore effectiveness, of quality control and assurance. The margins to make substantive and required improvements may not exist for the MOX manufacturer.

No significant safety analysis has been done by either MOX producers or regulators into the implications of quality control and quality assurance for the risk of accidents when MOX fuel is used in reactors. Nor has adequate independent analysis been done. 'Commercial confidentiality' is used as a smoke screen to prevent independent scrutiny of the quality control, quality assurance and the safety of MOX reactor fuel.

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