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A REVIEW OF THE HAZARDS AND RISKS RELATING TO THE PROPOSED TRANSPORTATION OF UNIRRADIATED MIXED OXIDE (MOX) FUEL FROM BNFL UK TO THE BEZNAU NUCLEAR POWER PLANT, SWITZERLAND

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HAZARDS AND RISKS OF DELIVERING UNIRRADIATED (MOX) TO BEZNAU

ABSTRACT

This review examines the hazards, risk and potential consequences associated with the transportation of plutonium bearing mixed oxide fuel (MOX) from the British Nuclear Fuels fuel fabrication works at Sellafield to the Beznau nuclear power station in Switzerland.

Details of how, when and by which route the delivery is to be made are not publicly available. However, the next scheduled refuelling outages of the two Beznau reactors are in June and July of 2003,§ so the delivery should be before then; it is known that the ro ro ferry *Atlantic Osprey* has been modified and readied so the route is likely include a sea leg (rather than flying direct as with previous MOX deliveries to Beznau); and if the transport arrangements for past deliveries of MOX to German plants are followed then it is believed that a specially adapted road vehicle, a SIFA articulated tractor unit, will be deployed to haul the MOX from Sellafield to the port of Workington. The receiving continental port is unknown, this could be in either France or Belgium, or possibly Germany, thence the road haulage continues to Beznau, most likely using the same SIFA-like vehicle. Similarly, the number of MOX fuel elements making up the delivery is not in the public domain, although a total consignment of 18 fuel elements would maintain the present MOX loading levels of the two reactors. The SIFA trailer payload capacity would permit a two of the current design of FS 69 flasks to be carried, each carrying two fuel elements, thus 5 separate deliveries to Beznau are required if just one SIFA trailer unit is used.

Whereas low enriched (<5%) uranium fuels, prior to irradiation, are not considered to represent a major health hazard in the event of a release from an accident or incident during the delivery, the release of the highly radio-toxic plutonium from a incident involving MOX fuel could result in a very significant health detriment indeed. Also, because the plutonium content of MOX fuel could be used in a weapon of mass destruction, either for a nuclear detonation device or in a so-called dirty bomb, international agreements require additional physical protection measures to be maintained throughout the transport phases.

Although the hijacking threat to a MOX transport consignment should not be entirely discounted, the review concludes that the greater risk of this form of plutonium proliferation being successfully completed would be at the fuel manufacturing plant or when the MOX is in store at the power station. Indeed, to hijack and abscond with the fuel whilst it is in transit is not considered practicable because such a venture would require considerable resources and, even if successful; absconding with the intact fuel would immediately attract state security personnel who could impede further movement of the fuel consignment.

The review considers two general means by which the respirable-sized radioactive particles of MOX fuel might be released and how such a release could impact upon the environment. These means encompass both accidents and, now in the post 11th September climate, intentional acts of sabotage, that is terrorist attack. It has to be acknowledged that the range of accidents and, particularly, accident severities must provide in extremis and/or novelty of circumstances opportunity to breach the flask and haulage trailer containment systems. Unlike accidents that are, after all, unintentional and unintelligent attacks, a terrorist attack will be intelligent and intentional, seeking out vulnerabilities of the system and it could include elements to hinder any post-incident countermeasure prepared to mitigate the consequences of the release. It is the latent ingenuity and outrageousness of the terrorist act that renders such so difficult to counter.

Therefore, for reasons of extremis and the novelty of accidents and, on the other hand, the ingenuity of a planned assault, the review does not attempt to compile specific accident/incident scenarios. Instead, the abnormal conditions at which the MOX flask would be expected to fail are determined from various research publications in the public domain. The broad range of past work enables the response of the flask to extreme thermal conditions to be its greatest weakness and route to failure. Such extremes of temperature and fire duration apply to both accidents, such as the high and sustained temperatures involved in ship and tunnel fires, and to circumstances that might be generated by any number of terrorist attacks. The flask structure (the steel lid and base shells) are also shown to be very susceptible to being punctured by an armoured piercing explosive round or crudely shaped explosive charge. A flask attacked in this way, especially if followed by a fierce fire within the confines of the transporting vehicle trailer, is reckoned to result in a very significant radioactive release to the environment.

Since the delivery route is not publicly available, it is not possible to identify specific population centres at risk. However for the UK leg of the transit, the relatively short distance between Sellafield and the port of Workington, about 30km, takes the consignment close to or through the urban centre of Whitehaven and, of course, into the heavily populated areas of the port itself. A serious fire at sea could put at risk coastal communities of the Irish, North-East Atlantic and North Seas, and the continental entry port that is also likely to be heavily populated. Once landed in continental Europe and on its way to Beznau, irrespective of whichever route it takes, the transit vehicle and its security convoy must pass through or nearby numerous centres of population, each at risk of exposure from any release from the flask because of accident or by terrorist act. As the convoy draws nearer Beznau its route becomes more certain, it is less able to deviate to avoid detection – this final stage of approaching, and passing through the region of the Beznau power station, like the outward run from Sellafield to Workington, is when the convoy might be considered to be most vulnerable to terrorist attack.

§ It now seems that because of delays in the final commissioning of the BNFL MOX fabrication plant the Beznau delivery is to be postponed until 2004.

The results of failure of the flask and haulage container are analysed for sample locations at Workington and Beznau for an extreme range of incident conditions, including for variations in release fraction, climatic condition, and so on. As a regulatory benchmark, a release equivalent to the maximum level nominated by the IAEA (A2) over the period of one week immediately following the incident is applied for fuel that hypothetically satisfies the 'low dispersion material' (LDM) definition. This release and its consequences are compared to releases generated by a variety of conditions that could arise by accident or, particularly, by terrorist attack. The results are given in terms of long-term mortality and include for various countermeasures that are assumed to be implemented in a timely and effective manner.

The analyses undertaken for this review are not intended to provide precise forecasts of the radioactive releases and consequences for the two localities sampled. This is because much greater detailed input is required to define the near field data, particularly in population density and meteorological conditions, for each locality. However, the results do provide both trends and indices of the probability of health impact should a release from a MOX consignment occur. In terms of radiation dose uptake and longer term health risk (probability of mortality and morbidity) the consequences arising from incidents of severe flask damage followed by fire, particularly in a confined space such as a ship hold or road tunnel, significant detriments extend up to and beyond 10km from the incident centre even with the appropriate countermeasures being implemented in a timely and effective manner. Even as the result of an extreme release, it is unlikely that and individual member of the public would immediately suffer from acute levels of exposure, but since the principal uptake route is via respiration the health detriment over the longer term (via organ dose) may be committed in the first few hours of the incident aftermath, particularly if there are delays in immediate sheltering and/or if the sheltering is ineffective.

Not surprisingly, it has been difficult to determine how the various national authorities intend to safeguard the consignment against terrorist action, either attempting to remove and abscond with the MOX fuel for its highly fissile plutonium content or to attack the convoy with intent to release the MOX fuel, that is exploiting the consignment as a crude 'dirty bomb'. There is no doubt that the national authorities have addressed these security issues but these may not be sufficient to overcome what is, after all, the fundamental weaknesses of transporting radioactive materials whereby the carriage is in the public domain – this is particularly so for road transportation where the transport route (the highway) is shared by others over which the carrier has little or no control.

So far as emergency preparedness applies, for the European Union Council states Directive 96/29/Euratom applies. In the UK this is interpreted to require the local authorities (typically the counties – Kent, Suffolk, etc) to prepare and maintain off-site emergency plans around the sites of nuclear installations and for the carrier to make plans for radioactive materials in carriage. However, radioactive material consignments undertaken in IAEA Type B flasks, such as the MOX deliveries, are exempt from the UK application of the Directive. So far as preparing for terrorist attack in the UK, there is considerable confusion over which authority is responsible, although for transport the Office of Civil Nuclear Security has some responsibility, although it was not permitted to respond directly on matters relating to the security of the Beznau MOX consignments.

Frontispiece: A blazing ventilation shaft of the Summit Tunnel, West Yorkshire, UK of December 1984 – the fire in the rail tunnel raged for over 48 hours with fire temperatures estimated in excess of 1,150°C.

HAZARDS AND RISKS OF DELIVERING UNIRRADIATED (MOX) TO BEZNAU

BEZNAU NUCLEAR POWER STATION

Switzerland operates three pressurised water reactors (PWR) and two boiling water reactors (BWR). The PWRs are at the twin reactor facility at Beznau[1] and a single unit at Gösgen, and the BWRs are at Mühlberg and Leibstadt. All three PWR reactors are currently licensed to accept mixed oxide (MOX) fuel[2] for commercial operation.

The reactors at Beznau are operated by the Swiss power utility Nordostschweizerische Kraftwerke AG (NOK), each rated to supply 350MW_e to the electricity distribution grid and, separately, a total of about 750MW*t* steam condensate heat is fed to mains for district heating and factory process use.[3] Since their respective commissioning in 1969 and 1971, both plants have been substantially modified and upgraded.[4]

Appendix I shows details of the (as built) reactor pressure vessel and fuel assemblies.

MOX FUEL UTILISATION AT BEZNAU[5]

Reprocessing contracts for Swiss fuel total about 1,077 tonnes of spent fuel that would yield approximately 6 tonnes of reactor grade plutonium. The NOK owned proportion of this derives from the reprocessing of about 880 tonnes of spent fuel from the Beznau plants, yielding approximately 2.2 tonnes of plutonium being separated by 2003.[6]

Four MOX fuel elements were first trialled in Beznau Unit 1 in or about 1978, some of which may have developed cladding faults within the first year of in-core operation. From 1984 prototype MOX cores were operated until 1988 when the first commercial MOX core was loaded. Unit 2 was first loaded with a commercial MOX core in 1984.[7] Some of the later MOX fuel batches have also been found to have developed cladding faults,[8] although NOK claims that until 1996 over nineteen years of MOX operation just a single MOX element failed because of debris fretting.[6]

The Beznau reactors are approved to receive a maximum of 48 MOX assemblies, which represents 40% of the core heavy metal mass. The latest refuelling of Unit 1 (2000) inserted 12 new uranium oxide fuel assemblies and 16 new Belgonucléaire MOX fuel assemblies to supplement the 4 BNFL MOX assemblies loaded in 1997, so the present MOX loading of Unit 1 is 16.5%. Unit 2 is MOX fuelled with 16 assemblies or 13% of the core load.[9,10]

The maximum plutonium (Pu-239) limit for Beznau is unknown, although typically each fuel element is likely to contain 6 to 10% Pu-239,[11] being of such PuO_2 content to match its intended position in the fuel core.

MOX FUEL SUPPLIERS

Previous batches of MOX fuel for Beznau have been supplied by Belgonucléaire and British Nuclear Fuels (BNFL). All previous MOX fuel supplied by BNFL has been manufactured in the now shut down prototype demonstration fuel fabrication plant (MDF) at Sellafield. The awaited Beznau MOX consignment is to be manufactured in the commercial MOX fuel plant at Sellafield that is presently undergoing final commissioning trials.

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MOX FUEL TRANSPORT & THE FLASK TYPES

All previous consignments of MOX from BNFL to Beznau have been by air, flown in by freighter aircraft from Carlisle Airport. The air transport mode from the United Kingdom was exceptional in overlying France, since all of the MOX fuel batches from Belgonucléaire have been overland through France.

The pattern of past BNFL MOX deliveries to Germany may indicate how the awaited Beznau deliveries are to be undertaken. These German deliveries have been via a road vehicle (tractor-trailer unit) picking up the MOX fuel at the fabrication facility at Sellafield, hauling it to the port where it was loaded onto the then German registered ro-ro ship *Arneb*,[12] thereafter completing the road journey from the German port, thence to the final destination. The tractor-trailer unit involved is referred to as a safety vehicle or 'SIFA' carrying a Siemens manufactured fuel flask, with the delivery convoy comprising transport, escort and communications control vehicles, all of which are armoured and fitted with vehicle tracking systems.[13] Both driver cabin and load compartment of the SIFA trailer unit are armoured, with the load compartment being 2050 x 2300 x 6070mm dimension, and of maximum payload of about 14 tonnes.

It is believed that the awaited shipment to Beznau is to follow this pattern. That is being transported by ship and road: The MOX fuel assemblies are to be packed within a Type B (U)F compliant flask that is to be road transported in an articulated vehicle (similar to the German SIFA) from the BNFL Sellafield plant to the Port of Workington. At Workington the transport vehicle is to load onto a ro-ro ferry *Atlantic Osprey* (previously registered as the *Arneb*) for the sea journey to an unnamed continental port. Thereafter, the final leg of the journey is with the MOX consignment wending its way overland by road to it destination at Beznau.[14]

The logic of the road and ro-ro ferry transport route combination is that the same road vehicle, typically a tractor unit and articulated trailer of the type shown in Appendix III, will be used throughout from start to end points of the journey, thus keeping, for any given consignment, the minimum number of transfers and the length of time that the cargo remains in transit.[15] This mode of transport also enables both dispatch and receipt sea ports to be switched to any port that can receive the *Atlantic Osprey*. Previously, the *Atlantic Osprey* (then operating as the *Arneb*) journeyed from the east coast port of Hull when delivering MOX fuel to Germany. In other words, Workington may not necessarily be the dispatching port for the Beznau MOX fuel.

The TNB 176/FS 69 flasks are at present used for the transport of MOX fuel assemblies in Belgium, France, and Switzerland. Depending on the type of security vehicle used for the transport, up to eight MOX fuel assemblies can be transported at a time. The FS 69 flask has a capacity for two fuel assemblies housed in a two-part external body, comprising a lower caisson and a removable lid. The fuel elements are held in a basket-like cradle, fabricated in aluminium boron alloy for criticality control, suspended from the caisson by elastic mounts for shock absorption.

The technical specification of each FS 69 flask system is:

PACKAGING/FLASK FOR MOX FUEL ASSEMBLIES – FS 69	
Capacity	Typically 2 assemblies
Typical Activity	11 PBq
Heat dissipation (max)	1.2 kW
Neutron Shielding	Fitted - External
Weight	6.6 tonne gross
Form	Rectangular Box
Dimensions	1.05 by 5.02m long

Holding two MOX assemblies, the individual flasks can be stacked into protective cradles in sets of twos or fours, giving an all up weight of about 13 tonnes and 26 tonnes respectively. For the road transit mode it is unlikely that the vehicle nett payload would be as high as 26 tonnes, so the likely maximum consignment per vehicle to Beznau would most probably be two FS 69 flasks containing in total four MOX assemblies.

In 1994 COGEMA developed another flask (FS 65) for unirradiated MOX fuel. This flask, the FS 65, can load one PWR 900 assembly, 2 BWR assemblies.[16]

PACKAGING/FLASK FOR MOX FUEL ASSEMBLIES – FS 65	
Capacity	1 PWR 900/1300 assembly or 2 BWR 900 assembly
Typical Activity	11 PBq
Max Heat Dissipation	1 to 1.1 kW
Neutron Shielding	Fitted – Resin Interlayer
Weight	5.6 tonne gross
Form	Stainless Steel Cylindrical, comprising two cylindrical shells, resign filled annulus, with internal fuel assembly basket + Aluminium Alloy External Impact Absorbing Frame
Dimensions	Cavity 4670 to 5000 by 430/500mm Ø Frame 980 by 930 X section 5.3 – 5.6m length

There is a further MOX flask under development in France, the MX 8, which will carry 8 MOX assemblies, and BNFL commenced development of a MOX fuel assembly flask in or about 1998. Known as 'Euromox' the BNFL flask is planned to enter service in 2003 for deliveries to Europe,[17] although there is no information on whether this new flask will be deployed for the Beznau delivery consignments.

Appendix II includes further diagrams and photographs of the above flask designs and prototypes.

NUMBER OF MOX TRANSITS

Very little information is available from BNFL on the size and delivery dates for the Beznau MOX order, other than a relatively dated BNFL statement that 18 elements have been ordered.[18] A consignment of 18 MOX elements would be sufficient to maintain one of the Beznau reactors at about 15% MOX fuelling, which is consistent with the present levels of MOX loading of the reactor cores. If so, a consignment of 18 elements would require five SIFA-type vehicle loads and most probably five distinctive journeys for a single tractor-trailer unit and its accompanying escort and communication vehicles.

Both Beznau Units 1 and 2 are on 18-month refuelling cycle with both reactors scheduled to commence outages during June and July 2003,[19] so it follows that the BNFL deliveries would be conveniently timed to meet these outage dates.

CATEGORY I MATERIAL TRANSPORTATION - THE REGULATORY FRAMEWORK

The transportation network across Europe generally adopts the International Atomic Energy Agency regulations, guidance notes, and codes of practice. These relate to both security of the consignment, the containment of the material, and the impact upon health should a radioactive release occur.

a) SECURITY

Unlike low enrichment uranium oxide nuclear fuel, there is an additional degree of physical protection required for MOX in transit. This is because of the possibility that the unauthorized removal of the material (plutonium, highly enriched uranium or uranium-233) could lead to the construction of a nuclear (or radioactive) explosive device by a technically competent group.

In this respect, unirradiated MOX fuel is defined as a *Category I*[20] material for which a number of security safeguards have to be in place. In making the appropriate security arrangements, considerable responsibility is placed upon the shipping state, here the United Kingdom,[21] to ensure that there is a clear transfer of responsibility at international border for maintaining the security of the transport vehicle and its contents. This includes for a change in the security or guarding personnel and the means of maintaining adequate levels of security while the consignment is in transit through that particular state - adequate levels of security requires that the guard force is assured close communication with appropriately armed response forces.[22]

In the UK the so-called *Competent Authority* that approves radioactive material in transit is the Radioactive Materials Transport Division (RMTD) of HMG Department for Transport (DfT). More specifically, the RMTD generally reviews the nuclear safety arrangements, although matters relating to security are undertaken by arrangement with the HMG Department of Trade and Industry's Office of Civil Nuclear Security (OCNS). These departmental responsibilities and jurisdictions[23] extend throughout the British Isles and its territorial waters (and British registered vessels) so, in effect, the UK approves the nuclear and security safety aspects of the consignment from the manufacturing plant (BNFL Sellafield) to and from the dispatching port (believed to be Workington) and up until the port of entry. At this point, the UK Competent Authority, being the *Shipping State* transfers to the *Receiving State* via one or two *Transit States* depending on the overland route to Switzerland.[21,24]

In Switzerland the Swiss Federal Office of Energy is the supervisory authority responsible for the physical protection of nuclear materials is transit as specified by a number of statutes,[25] with its Hauptabteilung für die Sicherheit de Kernanlagen (HSK) division assuming the role of *Competent Authority* once that the MOX shipment enters Swiss territory, although HSK also ascertains that the measures taken by all other parties involved in the transportation will be in conformity with its requirements.[68]

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The IAEA recommendations[20] on security, physical protection systems and sabotage prevention are specified in general terms, the salient features of which are as follows, with applicability to the UK shown [thus] and for Switzerland {thus}:[26]

- The physical protection system should be based on the evaluation of the threat and account should be taken of the emergency response capabilities.
- A design basis threat (DBT) developed from an evaluation of the threat of unauthorized removal of nuclear material and of sabotage of nuclear material is an essential element of the physical protection system.

  [In the UK the situation is confused insofar that Government ministers consider the DBT to be based on *'intelligence about the motives, intentions and capabilities of potential adversaries',*[27,28] which seems to imply that there is sufficient confidence to detect the intent of terrorist act before such are carried through.

  Relating to the REPPIR regulations,[58] the Nuclear Installations Inspectorate of the Health and Safety Executive have concocted the quite absurd reasoning for why it is unnecessary to include assessment of terrorist attack on the basis that *". . .that if a threat to the plant is judged by the operators, to fall below the limit of reasonable foreseeability then it does not need to be included in its submission to HSE. Given that there is no substantive evidence that a terrorist threat to a specific plant* (or transport mode) *and in a specific manner is reasonably foreseeable, HSE considers that it is quite correct that the reports of assessment do not need to consider this."*.[29]

  However, the recent Greenpeace UK incursions into the nuclear power plant at Sizewell showed that the UK security system may not be able unable to circumvent a terrorist attack.][30]

  {In Switzerland the Competent Authority is the Swiss nuclear safety regulator HSK which, although part of the Federal Office of Energy, is not responsible for assessing matters relating to physical protection of the MOX, this being, oddly, the Federal Office of Energy which is undertaken in accord with its own guidelines.[25]}

- Emergency plans for any needed response to unauthorized removal and subsequent unauthorized use of nuclear material or sabotage of nuclear material to support and supplement, when needed, those emergency plans prepared by the carriers

  [The claim in the UK is that the emergency plans (RADSAFE) prepared by the Carrier (here BNFL) are sufficiently flexible to be extended to cover acts of terrorism, although nothing is available in the public domain to substantiate this.][31]

  {Other than a somewhat limited statement that emergency planning in Switzerland is co-ordinated, nothing further is available for the Swiss authority.[32]}

- During international transport of nuclear material the responsibility for physical protection measures should be the subject of agreement between the States concerned and the following should be in place:
  - all States are Parties to the Convention on the Physical Protection of Nuclear Material (INFCIRC/274 Rev.1); or
  - have concluded with a formal agreement which ensures that physical protection arrangements are implemented; or
  - formally declare that their physical protection arrangements are implemented according to internationally accepted guidelines; or

  - have issued licences that contain appropriate physical protection provisions for the transport of the nuclear material.

- During international transport between two States sharing a common border, the State's responsibility for physical protection and the point at which physical protection responsibilities are transferred from one State to another should be the subject of an agreement between the States.[33]

  [In the UK these agreements are not publicly available documents].

  {Nothing available from the Swiss authority.}

- To ensure that physical protection measures are maintained in a condition capable of effectively responding to the design basis threat (DBT), the competent authority should ensure that evaluations are conducted by the Carrier (BNFL) of the transport, with these evaluations including administrative and technical measures, such as testing of detection, assessment and communications systems and reviews of the implementation of physical protection procedures and should also include exercises to test the training and readiness of guards and/or response forces.

  [Nothing has been published on whether the transportation flask (the FS 69 or FS 65 and the road vehicle - SIFA or similar) has been subject to trials to demonstrate its resistance to terrorist acts.]

Following events of 11 September, the potential vulnerabilities nuclear plant have attracted a great deal of attention[34] and some evaluation has been undertaken to assess the vulnerability and release of radioactivity from irradiated fuel transportation flasks[35] to terrorist attack and acts of sabotage, although nothing has been published specifically relating to unirradiated MOX transportation flasks.

However and in general, prior to the transport being undertaken the consignor is required to submit a *Summary Transport Plan* detailing the modes of transport, routes, ports, vehicles and packages involved. In the UK this summary is reviewed by the security authority (OCNS) and it is believed that BNFL carried out a trial replicating a shipment of MOX fuel in order to substantiate the Summary Plan. Further details of the *Summary Plan* and the shipment trial are not publicly available.

b) FLASK CONTAINMENT DESIGNS – NUCLEAR SAFETY

Category I quantities of plutonium for transportation, which includes unirradiated MOX fuel, must be transported in flasks that meet the International Atomic Energy Agency (IAEA)Type B criteria and, in addition, the flask design must account for the fissile nature of the consignment, as well as other transport mode-specific requirements.[36] Type B(U)F (Fissile) packages are used for transportation of fresh MOX fuel.[see also 23] As previously noted, overland consignments of unirradiated MOX fuel are carried in FS 69 flasks that are designated Type B(U)F, although other types of flask have been used over the 30 or so years that MOX fuel has been transported.[37]

The physical design and performance of flasks carrying Category I radioactive materials are required to satisfy domestic (state) legislation mostly derived from the IAEA *'Regulations for the Safe Transport of Radioactive Material'*,[38] and other regulations, etc., relating specifically to plutonium and

MOX fuel.[39] Essentially, these regulations (being nationally and internationally adopted) stipulate that Type B(U)/F packages meet the following functions:

- containment of the nuclear material
- shielding against radiations (gamma and neutrons)
- maintaining subcriticality conditions
- dissipation of residual heat

when subject to both normal and accidental conditions of transport.

The ability of flask designs to meet these requirements is determined by a series of tests throughout which the flask contents shall remained sealed within the flask.[40, 41] Essentially, the tests impose conditions that are equivalent to an impact of about 30 mph (from 9m height or 13.2 ms^{-1} upon impact) onto an unyielding surface, followed by a drop onto a fixed penetrator (rod) from 1m, and then exposed to fire with a flame temperature of 800^{o}C for 30 minutes. The approval process and certification of IAEA compliance are issued by the country that undertakes the design and manufacture of the flask and, although such documentation is available to the consigning, transit and receiving states, such remain confidential and are not available in the public domain.[68]

There is much criticism of the entirely empirical approach of the IAEA flask compliance regime,[42] particularly in that for accident (or sabotage) scenarios the conditions encountered by the flask may be more severe and, indeed, substantially different from those applied in the IAEA tests. Indeed, the first of the drop tests (9m) solely determines the ability of the flask not to leak during and following the very specific impact conditions of the test (particularly, a linear descent with no tumbling). Similarly, the punch test is aimed at demonstrating the ability of the flask containment to maintain a tolerable level of containment, although there is nothing requiring this test to be applied directly to the potentially weakest components of the flask.

Another very significant weakness is that the IAEA approach provides the opportunity for flasks to be designed to be test-specific, particularly now with very advanced computer-aided design techniques being available. Even extending the flask design beyond the requirements of the IAEA tests, there remains no compulsion and little incentive to carry out testing to a severity beyond what the standards require, particularly in that such tests are expensive and difficult.[43] Also, the IAEA tests include no specific provision or requirement for testing the resistance of the flask design to intentional actions to sabotage, damage or attempts to remove the radioactive contents. The assumption here seems to be that adequate safeguards will be in place to prevent the terrorist or saboteur gaining direct and unhindered access to the flask.

Some of these shortfalls are acknowledged by the IAEA and the radioactive materials carriers, although these, it is claimed, are by far more than offset by the flask design and construction being so conservative that such are able to withstand accidental forces and circumstances far more severe than the tests.[43]

c) THE TRANSPORT MODES AND ROUTE

In the UK the Maritime and Coastguard Agency (of the DfT) is the regulatory body concerned with the survey and certification of any United Kingdom registered vessels involved in the transport, which would include inspection and certification of the *Atlantic Osprey*.[44] For road transit the vehicle involved would be required to comply the European ADR agreement[45] and municipal legislation as this applies.

POTENTIAL WEAKNESSES IN FLASK SURETY

There are three weaknesses in the basis of the nuclear safety case as applied to transportation of nuclear materials. These relate to the assumed limit of the severity of damage to the flask and the fuel contents; the frequency of accidents and incidents; and that relatively large numbers of public could be in close proximity to the accident/incident site:

i) **Assumed Limit of Severity of Accidents and Incidents**

In adopting the IAEA tests as the flask compliance criteria, the underlying assumption is that real accidents and situations will not result in forces and circumstances greater than those experienced in the tests.

Accidents: There are many examples where the forces and circumstances of accidental situations by far exceed the severity applied by the IAEA tests.

Fires on board ships, both at sea and when berthed can involve very high temperatures over many hours. IMO records yield a mean duration of fires at sea to be 23 hours and for fires when berthed to be about 20 hours.[46] Fire temperatures on board ships are not readily available although past studies[47] assumed a temperature of 928^{o}C for both external (a pool of burning fuel on the sea surface) and internal machinery spaces. Similarly, there have been a number of fires[48] in road and rail tunnels of such severity that emergency crews could do little more than to allow the fires to burn themselves out.

Actual fires in confined spaces, such as ships and tunnels, give rise to temperatures and, particularly, durations that by far exceed the IAEA 800^{o}C and 30-minute thermal test specification.

Collisions and rammings in harbours and approaches could introduce very significant force systems into the flask structure, far in excess of the IAEA 9m impact test.[49]

Terrorist Acts: Not only is the IAEA empirical approach flawed because it cannot conceivably cater for all severities of damage, it completely omits to account for any contrived situations. That is the IAEA test regime is drawn from accidental circumstances and, because accidents are accidental and unintelligent events, this approach cannot necessarily counter intentional and intelligent attacks on the system. An intelligent and intentional act, that is an act of terrorism, is likely to seek out the vulnerable parts of the flask and its transport system, tailoring the nature of the act to maximize damage and the radiological consequences.

Moreover, a terrorist attack might also be expected to include elements intended to hinder or harass the implementation of countermeasures to minimize either or both the magnitude of the release and radiation uptake in the immediate aftermath of the attack.

ii) **Frequency of Accidents and Incidents**

A second line of defence promulgated in the nuclear safety case is that severely damaging accidents and situations are acceptably infrequent so as not to be credible.

***A Priori* Accidents:** If it is accepted that real accidents could give rise to circumstance that would fail the flask containment (ie ship and tunnel fires, rammings, etc) then the frequency of occurrence of failure must be acceptable. This foundation is usually developed into the composite that untoward accidents and incidents must be of *acceptable risk* and result in *tolerable consequences*. This interprets to:

- Severely damaging events must be acceptably infrequent;
- the outcome (radioactive release) from all other events (ie credible events) must be tolerable (inconsequential); and
- if the radioactive release were to be significant then the emergency procedures and countermeasures would be effective in mitigating the consequences to a tolerable level.

At Sea

For sea passages the probabilities of collisions, ramming, grounding and fire outbreak are as follows:[46,47,50]

LOCATION	PROBABILITY PER OUTWARD BOUND TRANSIT			
	COLLISION	RAMMING	GROUNDING	FIRE/EXPLOSION[51]
Port & Approaches	$1.90\ 10^{-4}$	$4.87\ 10^{-4}$	$7.79\ 10^{-4}$	$1.9\ 10^{-4}$
Continental Shelf	$1.82\ 10^{-6}$	-	-	$2.70\ 10^{-8}$
Continental Slope	$3.63\ 10^{-6}$	-	-	$5.40\ 10^{-8}$
Deep Ocean	$4.13\ 10^{-5}$	-	-	$4.79\ 10^{-6}$
TOTALS	**$2.37\ 10^{-4}$**	**$4.87\ 10^{-4}$**		
		$7.24\ 10^{-4}$	**$7.79\ 10^{-4}$**	
			$1.50\ 10^{-3}$	**$1.95\ 10^{-4}$**
				$1.70\ 10^{-3}$

The ship collision, ramming, grounding and fire/explosion probabilities are those assumed for an advanced radioactive waste concept ship design.[47] The highest risk of collision and rammings occurs in harbours and when navigating the approaches which derives from a collision per 100,000 encounters, giving a risk per outward bound loaded voyage of about once every ($1/2.37.10^{-4}$=) four thousand years. Similarly, the total risk of an incident at sea is once every ($1/1.70\ 10^{-3}$=) 590 years or thereabouts for each loaded sailing.

Applying this reasoning to the *Atlantic Osprey* ro-ro ferry undertaking five loaded sailings for the Beznau MOX fuel delivery, the overall risk increases to an equivalent of about once every one hundred years for the entire consignment of MOX.[52]

On the Roads

For movement by road, the number of accidents anticipated for the distance travelled by a type of vehicle on a class of road may be crudely forecast by referring to past accident data for those road-vehicle circumstances.

The vehicles making up the MOX delivery convoy will include a SIFA-like articulated unit, possibly two escort and a single communications control vehicle.[53] The convoy road route includes the outward leg from Sellafield to Workington and then from some Continental port to the Beznau power station – in all, about 1,000km. The transit would run along trunk roads and motorways. For the five delivery journeys envisaged for the Beznau shipment, the total vehicle road distance would be (4*5*1000=) 20,000 vehicle-km or about 12,500 vehicle miles, excluding motorcycle outriders and similar.

The reliability of probabilistic analysis applied to such a specialised group of vehicles is unproven, principally because the statistics of road traffic accident generally derive from accidents involving vehicles travelling independently and not within a convoy. Also, such statistics are only formally reported and maintained for accidents involving injury or death and not for accidents resulting only in damage.[54] Another difficulty is with defining the severity of accident and the type of vehicles involved, as acknowledged by a past study into the risk of accident associated with the transportation of radioactive waste.[55] This study assumed for a similar class of heavy goods vehicle (HGV) a probability of severely damaging accidents for single vehicles to be 96.10^{-9} per mile for motorway travel, with higher probabilities of 192.10^{-9} per mile for UK 'A' class trunk roads giving a mean probability of accident of 144.10^{-9} per vehicle mile.

Applied directly to the movement of the SIFA-like convoy the mean probability yields a risk of accident involving serious damage to any one vehicle, although not necessarily the MOX fuel transporter, of about 2.10^{-3} over the 5 delivery journeys. That is a chance of about once every 500 years. An alternative way of defining a set of damaging accidents is to consider heavy goods vehicles (articulated in this case) which have either overturned or been struck by another large vehicle.[56] This prescribed set of accident conditions yields higher accident frequencies of x2 to x3, thus increasing the chances of accidents cited previously to about once every 170 to 250 years.

The statistics employed here are for the generalised movement of heavy goods vehicles and not for vehicles travelling bunched in convoy. It might be argued that a well-ordered convoy represents, for the purpose of accident frequency analysis, a much longer single vehicle with a correspondingly lower accident frequency. Conversely, it might be that in maintaining convoy formation, the grouping vehicles are more at risk of accident or that other vehicles negotiating past the convoy are more at risk of interaction and accident with the convoy. Relatively slow moving convoys are not common on the United Kingdom road network and this factor alone may give rise to a higher accident frequency and, whatever, the current accident databases do not isolate accident statistics for convoy movements.

It may be concluded that it is not possible to forecast reliably the susceptibility of the SIFA-like MOX fuel delivery convoy to road traffic accidents. Like any other road vehicle, the SIFA articulated unit is at risk of road accident and, of course, accidents can occur at any time. In transporting MOX by road, the carrier (BNFL) is only able to maintain direct control over one small element of the overall safety composite — this element comprises the design and maintenance of the SIFA convoy vehicles and with the training and discipline of the convoy personnel. Yet passing alongside MOX convoy will be numerous and untrained individuals, in control of vehicles in varying states of repair and road worthiness, any of which could be carrying an extremely hazardous cargo, and so on and so forth. The risk and probability of a road accident involving a MOX delivery convoy is incalculable in these circumstances.[57]

Acts of Terrorism: Overall, the nuclear industry underpins nuclear safety against natural and accidentally occurring hazards on a basis of 'as chance would have it', and it provides protection against human error by designing the systems and equipment to be tolerant and/or independent of human action (or inaction). Much the same probabilistic approach applies to the transportation of radioactive materials, including unirradiated MOX fuel.

This combined approach of gauging the risk by probabilistic assessment and treating the human operators as inconsequential dummies may have some effect in safeguarding nuclear systems against accidents and unintentional human error, but it may prove to be woefully ineffective against intentional and intelligently driven acts of terrorism. Of course, the probability or chance of the occurrence of a malicious human act, such as the terrorist attack of 11th September, cannot be determined by classical *a priori* probabilistic means.

This is particularly so for when, as with the MOX fuel deliveries, the nuclear system moves out of the physically protective confines of the nuclear plant, particularly when it is journeying on roads. For this situation, it is not possible to establish an impenetrable security boundary around the convoy, like the security fencing around a nuclear power station; and other and unchecked vehicles are free to move into close proximity to the convoy. Also, the surrounding terrain along the convoy route is constantly changing, providing nooks and crannies where the terrorists may hide and under-road culverts and the like where explosives may be placed. Although the road can be pre-checked before the convoy's arrival, because the route is along public roads it may be possible for terrorists to install themselves in the intervening period between route checking and the convoy's passing.

Should the MOX convoy be identified as a target by terrorists and if it is attacked, the supporting security personnel may be disabled and there may not be sufficient time for the response force to arrive at the scene before a significant radioactive release has occurred by some means or other[66] which, it might be argued, is particularly applicable to the sea leg of the delivery route. However, the UK DTi considers that the security personnel accompanying the convoy will be sufficient in all foreseeable circumstances to immediately respond, thereby implying there to be no need for other security forces to be held in reserve.[28]

iii) **Proximity of Large Numbers of Public – Emergency Planning**

The fundamental weakness in the nuclear safety case applied to the transportation of unirradiated MOX fuel is that the transport route passes through and nearby centres of population, thus placing at risk of radiation exposure relatively large numbers of people.

Emergencies involving radioactivity in the UK are covered by the *Radiation (Emergency Preparedness & Public Information) Regulations* (REPPIR).[58] These regulations require the Carrier to prepare an emergency plan for Type A packaged consignments under shipment by rail, although Type B flasks are exempted from REPPIR for rail and road shipments. Instead, road transport of radioactive consignments in the UK is covered by modal legislation.[59]

Separately, an emergency plan known as RADSAFE, organised by a consortium of carriers and is based on the requirements of the emergency services, drawing on the principles of the national *Chemsafe* plan, is maintained nationwide. These and other contingency arrangements are complemented by the National Arrangements for Incidents involving Radioactivity (NAIR).

RADSAFE exercises are attended by the UK nuclear safety regulator, the Nuclear Installations Inspectorate (NII) of the Health and Safety Executive. The NII has stated that it has not attended any RADSAFE exercises that simulate and which are representative of the road transport legs of the Beznau MOX deliveries.[60] In other words, the overland UK section of the delivery route is likely to be unpractised.

In summary: Movement of nuclear materials is inherently risky in both terms of severe accident and terrorist attack. Not all accident scenarios and accident severities can be foreseen; it is only possible to maintain a limited security cordon around the flask and its consignment; the transportation route will invariably pass through or nearby centres of population; terrorists are able to seek out and exploit vulnerabilities in the transport arrangements and localities on the route; and emergency planning is difficult to maintain over the entire route.

COMPARISON OF SECURITY MEASURES WITH PREVIOUS SEA SHIPMENTS OF MOX

Previous shipments of MOX fuel from BNFL Sellafield to Japan have been completed under very stringent security conditions, via an armed radioactive waste carrier accompanied by a second armed vessel.[61] The BNFL MOX fuel delivery of eight assemblies was rejected by the Japanese customer when, after a series of allegations from Japanese protest groups, BNFL admitted that quality control data had been falsified at Sellafield. This batch of MOX fuel was returned to the United Kingdom in September 2002, again using heavily armed vessels shadowed by, so it is believed, a Royal Navy nuclear powered submarine.[62]

Physical protection measures for the Europe-Japan-Europe MOX movements included the fuel assemblies moved by rail in a 92 tonne Excellox 4 flask under armed escort to the dedicated radioactive materials handling dock at Barrow-in-Furness, thereafter on the high seas in a double-bottomed, twin-engine freighter, armed with 30mm naval canon.[14,63] By comparison the *Atlantic Osprey* is a single hulled, single engine ro-ro ferry that, apparently, is not naval canon armed, although it may have been recently fitted with additional accommodation for security personnel.[64]

The apparent anomaly between the level of security and physical protection between past Japanese and the proposed Beznau MOX shipment was raised with HM Secretary of State for the Department of Trade and Industry.[65] The response is baffling in the least, stating that

> *"The security measures that have been adopted for such shipments are those which best meet the physical protection requirements. They have been approved by all relevant Government regulators, are designed to cope with any potential threat and ensure that the security risks associated with the export of MOX are negligible . . . The security arrangements for shipments of MOX from Europe to Japan are different from those in place for transporting MOX within Europe. Primarily, this is due to the fact that ships carrying MOX to Japan travel long distances and the type of support that could be provided very quickly from the UK to a vessel travelling only between the UK and ports in Europe may not always be available to them."*

In fact, this statement seems to be at odds with PNTL's (the BNFL shipping division) claim that its arranged resources will have a qualified response team to an emergency site involving one of its ships on the open sea, anywhere in the world, within less than 24 hours.[66]

HM DTi claims further justification of the difference between the Japanese and Beznau shipments to be:

> *"It is also the case that the Japanese owned plutonium contained in MOX that is exported to Japan arises from uranium fuel of United States (US) origin. The US Government retains certain rights and duties in respect of the physical protection and safeguarding of this."*[67]

and providing the final reassurance that

> *"However, I can assure you that the transport of fresh MOX fuel represents no credible risk to anyone's safety or to the environment and that the export of MOX to Europe and Japan is carried out in line with all relevant commitments and recommendations on the application of international nuclear materials safeguards, nuclear non-proliferation and the physical protection of special nuclear materials."*

So for MOX fuel, the International Atomic Energy Agency (IAEA) requires extra safeguards not just to maintain security in terms of proliferation, but also specifying the highest classification (in strength and containment) of transport flask (Type B(U)F) in order to minimize the radioactive release in the event of an accident/incident. However, on its part, HM Government states there to be '*no credible risk to anyone's safety or to the environment*', implying that the US requirement for an armed escort vessel in attendance is unnecessary for European deliveries. So far as HMG's undertaking and measures to *'ensure that the security risks . . . are negligible'* it remains steadfastly disinclined to demonstrate this even in principle as its replies to Beznau-specific enquiries show.[68]

MOX FUEL – MAKE-UP AND DURABILITY

Mixed Oxide (MOX) nuclear fuel is a blend of uranium and plutonium oxides, typically containing between 3 to 10% plutonium Pu^{239} depending on the specific design of the host nuclear reactor,[69] with the remainder bulk being depleted uranium (U^{238}).[70,71,72] In terms of accountancy, the plutonium contained within the Beznau MOX consignment would be drawn down from the stockpile of plutonium extracted from Nordostschweizerische Kraftwerke AG fuel contracted to be reprocessed, although in reality the plutonium source could be any one or more of a variety of fuels previously reprocessed by BNFL.[73]

Whereas uranium oxide fuels, prior to irradiation, are not considered to represent a major health hazard in the event of a release as a result of an accident during delivery to the nuclear power plant, the release of the highly radio-toxic plutonium from a delivery transportation accident involving MOX fuel could result in a very significant health detriment indeed. Particularly significant in the health detriment of a release is the fractions of americium-241 and plutonium-238 contained within the MOX fuel.

In promoting the safety case for the delivery transportation of unirradiated MOX fuel, the nuclear industry relies upon two strings of argument. First, it claims that the flasks used for the transportation of the fuel are failsafe under all reasonably foreseeable accident conditions and that, second, should, inconceivably, a flask fail it assumes[74] MOX fuel as a low dispersible material (LDM). LDM means that if the normally fully clad fuel is exposed to air, particularly where the fuel is subject to a fire environment, then the formation and release of particulate from the outer surface, or broken surfaces, of the fuel pellet will be minimal. Setting an upper limit to the release fraction in this way also sets an upper limit to the environmental impact and health detriment arising from accidents involving MOX under transportation. Although the nuclear industry is strident in its claim that MOX is LDM,[75] it offers little technical substantiation in support, there being just two publicly available technical papers on this.[76,77,78,79,80]

It is of interest to note that in its application to the UK *Competent Authority* (the DfT Division of Radioactive Materials Transport) BNFL did not apply for the MOX fuel to be considered as LDM (Appendix IV), although it should be noted that there is no such requirement for radioactive materials transported in the surface modes within type B(U) or B(M) packages (ie the LDM requirements applies on to air transportation.)

The final (BNFL) pellet (specified) properties are as follows[119]

BNFL SHORT BINDERLESS MIXED OXIDE PELLET CHARACTERISTICS		
Geometric Density	10.45 +/-0.17 g/cm^3	Green pellet density >6 g/cm^3
Surface Roughness	0.43 micro-radians	0.159 micro-radians sd
Hydrogen Inclusion	0.27 ppm	0.14 sd – no in store uptake
Oxygen/Metal Ratio	~2.000	
Grain Size	7.4 micron average	0.54 micron sd

Sinter temperature	1,650°C max 24 hours	4%Hz/Ar atm + trace CO2 grain growth via Oxygen potential to limit Pu reduction to +3 valency state
Open Pore Density	GD-ID 0.016 W/cm^3	Water immersion + Wetting agent

Each Beznau (uranium oxide) fuel assembly is based on a 14 x 14 matrix of 179 fuel pins or rods. Each pin is made up of a long zircaloy tube of 0.62mm wall thickness holding a stack of sintered pellets, each of 9.32mm diameter and 15.24mm length, with each pin weighing 2.12kg (U) weight. The uranium mass of the 179-pin fuel assembly is 378.9kg (U). Although pellet length may differ, the MOX fuel pin design, assembly dimensions and weight would be much the same as the Beznau uranium units. Appendix II shows a single fuel assembly for the Beznau reactors.

The Beznau reactors use 'all plutonium' fuel assemblies with the overall fissile plutonium content matched to one of three enrichment zones in the reactor core. The majority of the fuel pins or rods in the assembly contain high content plutonium matched to be equivalent to the surrounding uranium fuel assemblies. To avoid power peaking along the edges and, particularly, at the corners of the fuel assembly lower plutonium content pins are deployed.

Radionuclide composition of the Beznau MOX fuel is not published, although it is reasonable to assume that the plutonium-239 content would be at least 6 to 7% weight plutonium dioxide (PuO_2), enriched to 70% weight of plutonium, a high proportion of which is Pu239, with up to 6,000 ppm Am^{241} together with other plutonium isotope impurities present, and the balance was made up of depleted uranium [81,82] - some variation around this assumed mean will be applied to suit the fuel core enrichment zones and, particularly how this to be applied to the Beznau reactor fuel cores is not known.[83] The composition of the so-called reactor and MOX plutonium grades are available from a variety of sources although these do not precisely fit the outline Beznau MOX fuel specification.[84]

In a radionuclide sense, MOX fuel is unstable with the plutonium dioxide component of MOX being alpha active resulting in a degree of self-heating from absorption of the energy of the alpha particles, although equilibrium temperatures are low.[85] In the longer term, the continuing growth of the Pu^{241} daughter product Am^{241} (americium) renders MOX increasingly more gamma active[86] and, continuing emissions of alpha particles from both the americium and plutonium convert to helium atoms which results in a build up of pressure inside the pellet internals and cladding sheath (cladding gap) over any prolonged period of storage before loading into the reactor core.[87]

SECURITY OF MOX FUEL – THE PROLIFERATION ISSUE

As plutonium becomes more available worldwide, and the manufacture and delivery of MOX fuel strongly contributes to this, it is increasingly possible for a terrorist group to steal, or otherwise illegally acquire, plutonium bearing materials that, once extracted, the plutonium could be used to fabricate a nuclear explosive device or, more simply, a dirty bomb.[88]

However, for terrorists to abscond with one or a number of MOX fuel elements[89] whilst in transit, either at sea in coastal waters or on the roads, would require considerable resources, first, to challenge the security arrangements of the convoy and, second and once the MOX consignment has been seized to abscond with the fuel with detection and restrain from state authorities. A more tenable means of obtaining this material, it might be argued, would be removal from the fabrication and/or storage plants and alteration of the inventory records.

STABILITY OF UNIRRADIATED MOX FUEL UNDER ABNORMAL CONDITIONS

Thermal - Oxidation: The melting point of the MOX refractory ceramic is approximately 2,700°C[90] but surface oxidation initiates at a significantly lower temperature of around 250°C[91] if the fuel is exposed to air.[92] At relatively low temperatures exposed MOX pellets produce respirable-sized particles[93] following relatively short exposure periods. For example, 1.87% of the initial mass was rendered respirable-sized particulate when MOX fuel is exposed at 430°C for 15 minutes, as compared to 0.01% at 800°C. Pulverisation at the lower temperature could result in substantial particulate release in smouldering type fires that could last for many hours.[94,95]

During normal transportation conditions the MOX fuel oxides (PuO_2 and UO_2) are stable so there is little risk of further oxidation to the higher oxide states, although there is at least one past incident where a dry flask carrying irradiated fuel released an aerosol of UO_3 when it arrived at the Battelle Laboratory in the United States.[96] The maximum temperature of this particular consignment of fuel, arising from the residual heat of natural radioactive decay, was reckoned not to have exceeded 282°C at the fuel surface. This oxidation formed aerosol at about 280°C is consistent with experimental work completed quite independently elsewhere.[91]

Ship and tunnel fires[97,98] could be very demanding on the flask containment. Ramming and collisions forces between ships at sea can invoke energy levels of around 3.10^6kN-m with temperatures and, particularly, the duration of fires on board being significantly higher and longer than the IAEA thermal test.[99] The International Maritime Organisation (IMO) records giving the mean duration of ship fires at sea to be about 23 hours with mean temperatures in excess of 980°C, sometimes reaching in excess of 1,000°C.

Once that flask surety has failed the remaining containment is limited to the fuel cladding, which comprises a thin sheath of zirconium alloy (zircaloy) forming the fuel pin that encapsulates the stack of fuel pellets. Zircaloy is not reactive at low temperatures but violently exothermic reactions occur in the region of 850°C to 1,000°C, particularly in the presence of superheated steam,[100] evolving hydrogen which can subsequent rapidly burn or explode.

The next potential stage for dispersion of the fuel is oxidation of the uranium matrix of the fuel from UO_2 to U_3O_8, which commences in air exposures at around 282°C.[101] Since the oxidation chemistry of plutonium is very similar to that of uranium, the same dispersal mechanisms will apply but, because the milling size of the plutonium oxide is minimal, to prevent nuclear 'clumping' within the fuel pellet, the particle size of the release may be smaller than that experience for solely uranium oxide fuel.[102, 103]

Mechanical Shock/Loading: MOX ceramic pellets are brittle and will shatter when exposed to high-energy impacts. For example, experiments on depleted uranium fuel pellets subjected to impact energy of 0.1 J/g resulted in a release of 0.5% (of the initial mass) particles of dispersible size,[43,104] although realistic accident impact levels would be considerably higher[105] at about 4 J/g or higher under extreme air or ship transport conditions but the first two stages of containment, the fuel cladding and surfaces of the fuel assembly, and flask even if failed would arrest the subsequent low (virtually zero) energy dispersal of the particles..

Explosive Loading: Nothing is published on the response to MOX fuel elements and pellets to explosive loading. However, there is now an emerging field of literature on the response of irradiated uranium dioxide fuel and fuel transport flasks when subject to explosion,[106,107,108,109,110] although these relate generally to irradiated uranium dioxide fuels across a variety of flask designs.

Following events of 11 September, terrorist attack against any nuclear consignment in transit cannot be discounted and, in recent months, the threat has heightened in Europe (apparently from the ongoing number of arrests). Certainly, some national and international terrorist groups have the knowledge and skills to manufacture powerful ordnance sufficient to breach the carrying vehicle and the flask itself. Also, there is a variety of anti-tank and armour piercing weapons available in the military domain (and supposedly on the international arms black market) with virtually all of these weapons capable of breaching the typically carbon steel flask walls.[111] Certain armour piercing rounds comprise two stages, first a high brisance armour piercing stage and, once that the armour has been pierced, a second stage firing an explosive intended to obliterate the internals of the target. Most anti-tank weapons and their rounds are portable and capable of being handled by one or a few individuals in urban environments.[112]

In the early 1990s the West German Federal Ministry of Environment, Nature Protection and Reactor Safety (BMU) required physical testing of transportation flasks against shaped explosive charge, with the practical trials were carried out in the Centre d'Étude de Gramat (CEG) in France under the supervisions of BMU in 1992, although little further information on these trials is available.[113] Similar trials simulating sabotage on irradiated fuel flasks were undertaken in the early 1980s and 1990s in the United States.[114] In the United Kingdom, the National Radiological Protection Board undertook the analysis of a radioactive release from an irradiated PWR fuel flask that had be hypothetically subject to terrorist attack by an armoured piercing round, thus setting the parameters for a radioactive release initiated by explosive conditions[115] - the release fractions adopted in this NRPB study ranged 1 x 10^{-4} to 1 x 10^{-3}.

More recently, there is one specific research paper that quantifies the release fraction of irradiated fuel following breach of the containment flask by an explosive charge,[116] working on the basis of the quantity of respirable spent fuel aerosol that might be produced by a terrorist attack. The experimental-based work yields two relevant source terms that lead to values of 6 x 10^{-5} to 8 x 10^{-4} g of respirable surrogate spent fuel aerosol released from the cask per gram of surrogate fuel matrix disrupted by a sabotage attack using high-energy device acting on the exterior surface of the flask. That the explosive charge was not in physical contact with the fuel assemblies and the aerosol/particulates given off primarily derive from the shock and blast loading and the release fractions relate only to the quantity of fuel that was expelled from the flask (ie excludes fragments and particles of fuel remaining in the flask). The surrogate fuel used in this work comprised unirradiated U^{238} sintered oxide pellets sheathed into fuel pins and arranged as fuel assemblies for which the results were then factored up (x3) to model spent or irradiated fuel.

The size distribution of the surrogate fuel (U-238) particles released was:

	POST-DETONATION PRESSURE INSIDE FLASK	
EQUIV AERODYNAMIC Ø [μm]	RELEASE NORMAL g	RELEASE AT 0.8 BAR g
< 12.5	1.0	0.4
12.5 - 25	0.7	0.1
25 - 50	1.0	0.1
50 - 100	0.9	0.1

Analysis of the dispersion following an explosive attack on a flask of irradiated fuel[115] utilized data from a source that is no longer in publication.[117] However, others referring to this work give the release of respirable-sized particles from the flask to range from 1 x 10^{-6} to 1 x 10^{-3} for actinides in oxide form (which is generally the level assumed for other fission and activation products). If a factor of 1/3 is adopted to convert from the irradiated and damaged fuel then the expected release from fresh MOX fuel would be expected to range from 3×10^{-7} to 3×10^{-4} which is consistent with the published experimental work.[116]

There are a number of reservations to be considered in adapting this data to any projected release from a MOX shipment.

In the main, the experimental trials were conducted on the much more robust Castor design of irradiated fuel transport flask with side walls of 150 to 200mm solid carbon steel and of about 100 tonnes weight, compared to the much lighter MOX fuel FS 69 flask at 6.6 tonnes with the side walls made up as a sandwich structure of relatively thin steel shells separated by a non-structural ablative infill – as previously noted, compliance with the IAEA would not necessarily provide a uniform resistance to explosive attack across the range of flask designs. Penetration of the Castor flask was caused by a shaped explosive charge with the aerosol being generated primarily by shock loading to the fuel pins, whereas an armour-piercing round would be likely to penetrate to inside the flask to deliver a second shot of explosive energy at high temperature once it had penetrated the armoured skin.

The resulting aerosol formed, particularly the range and dominance of a particle size, is dependent upon the amount of particles present at the time of fuel pin cladding failure, the dispersion of these particles within the fuel pellets, the inherent size of the particles in the matrix of the fuel, along with any retention or 'plating out' and retention of fuel particles on the surfaces of the fuel assembly, flask walls and breach through the vehicle container.

The ejection of the aerosol is via those particles caught up in the highly turbulent jet stream that puffs out of the flask internals during the short spell when external and internal pressures are equalizing. In the reported trials the aerosol release was very short term, with less than 1% of the <12.5µm particles being released after 30 seconds. However, this period of release extends considerably if the flask sustains greater damage and/or if fire breaks out in or about the vehicle trailer unit.

Another very significant factor that determines the health consequences of the radioactive release is the particle size. In the reported trials, the surrogate fuel gave off a range of particle sizes of which about 25 to 50% (depending on the flask pressure) were of respirable size (say <12.5).[118] Unfortunately, little information is provided on the make-up of the U^{238} surrogate fuel, although if typical of uranium oxide the pre-sintering milled powder could be relatively large compared with the much finer milling sieves used in the BNFL short binderless manufacturing process yielding an average grain size for its MOX fuel of 7.5µm.[119] Thus, the expectation is that MOX fuel subjected to the same explosive conditions would most probably yield a larger fraction of finer, respirable-sized particles.

Of course, it would be necessary to breach the SIFA-like trailer unit in order to attack the MOX flask(s) within, although the armour plating of the trailer must be relatively light gauge because, for this size of vehicle, armouring on the scale adopted for military fighting vehicles would result in excessive axle loads. Thus, a two shot attack would be necessary, first to access into the trailer unit and then a second round to breach the MOX fuel flask(s).

Explosions and Fire Combinations: Other potential attack modes could include a vehicle (suicide) bomb pulling up alongside and detonating close to the SIFA vehicle whilst it is underway; the SIFA convoy being brought to a halt and entrapped within a road tunnel by petroleum loaded road tankers that are subsequently ignited and left to burn; and so and so forth as discussed in some detail by recently published work.[24]

An explosive disruption followed by fire provides opportunity for increased radioactive release from the fuel: First, as a puff of aerosol of fuel particles aerosolised by the explosive force and second, as prolonged as the fire itself, as further particles of the damaged and likely oxidising fuel are entrapped and swept into the rising plume of the fire.

In summary: Many of the works cited above were analyses or analytical extensions of measurements of surrogate spent (irradiated) fuel aerosols produced in sabotage-like configurations. The correlation between various test has been poor with a projection range of approximately 10 (0.7 to 12) between the lowest and highest estimates of the ratio of spent fuel respirable aerosol mass to surrogate respirable aerosol mass – this same order of variation is also most likely to apply to MOX fuels, although to date there is nothing published on the behaviour of MOX fuel under explosive loadings.

Prolonged fires can result in fire conditions (temperature and duration) that will break down the matrix of the fuel and give rise to a significant release fraction of aerosol – actual fires in road and rail tunnels, and on board ships when at sea and when berthed, have demonstrated that thermal conditions are sufficiently severe to degrade the fuel and result in a release of fuel particles.

The release fractions might be summarised as follows:

CONDITION	RELEASE FRACTION	REF	COMMENTS
Fire at 800^{o}C	1.E-4	93	
Impact at 0.1J/g	5.E-3	104	Containment of the fuel unknown
Explosive – Excellox Flask – No SIFA second containment	1.E-4 to 1.E-3	115	Probably extracted from Ref 117
ditto	6.E-5 to 8.E-4	116	Adapted from spent to surrogate fuel
Fire 2 hours	3.3.E-7	117	ditto
Explosion	1.E-1	24	Terrorist scenario on plutonium dioxide powder in FS47 flask shipment

It would not be particularly astute reasoning to arrive at the conclusion that a combination of explosive charge followed by a severe and prolonged fire in a confined space would maximise the release of radioactive particles from MOX fuel.

Given the recent and likely continuing climate of terrorist threat, deliveries of MOX fuel are not, it might be argued, adequately defended against this threat. First, the claim of the UK authorities that the *'motives, intentions and capabilities of potential adversaries*[27] can be identified before the attack is somewhat shallow in light of the recent Greenpeace UK intrusions into the Sizewell B nuclear power station which were unchallenged until the activists were established inside the security compounds and, on the second occasion, actually inside safety critical buildings.[120] Secondly, there is no demonstration that the delivery route can be absolutely safeguarded against terrorist attack, nor is it clear why the exceptional levels of security (heavily armed vessels, etc...) adopted for the Japanese MOX delivery and return voyages are not believed to be necessary for the Beznau MOX deliveries. Thirdly, past research and experimental programmes, involving shaped charges and propelled round attack on actual fuel flasks carried out in the United States show that the heavily shielded CASTOR type flasks cannot maintain surety under such attack, yet the most likely transport flask to be used for the Beznau delivery is considerably lighter and, arguably, less resistant to explosive charge, than the types and construction of the US test flasks.

Large and ASSOCIATES Consulting Engineers

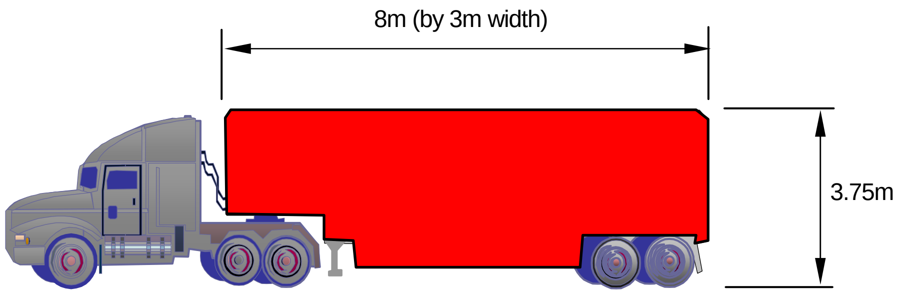
ACCIDENT AND SABOTAGE CONDITIONS – THE RADIOLOGICAL CONSEQUENCES

There have occurred a number of accidental releases of plutonium bearing materials arising from accidental circumstances and intentional experiments. Known accidents include the loss and burning of nuclear weapons (USAF Thule and Palomares) and experiments deliberately dispersing plutonium to simulate accidents involving nuclear weapons (Maralinga Vixen Trials, Australia),[121,122,57] although there is hardly any worthwhile epidemiological data to be gathered from these releases of plutonium.

These past events demonstrate that a release of plutonium bearing materials (from a elemental metal state and not in the sintered oxide form as considered here), when in an aerosol/particulate form, can result in dispersion and contamination for considerable distances downwind at the dictate of the climatic and other conditions prevalent at the time. The Maralinga trials (which were controlled and undertaken under somewhat contrived extreme conditions) showed that a plutonium oxide respiratory hazard persisted beyond 17 to 30 miles (~27 to 58km) downwind of the release site.

The envelop of conditions and circumstances that will determine the main phases of a radioactive release, notably the release fraction, its dispersion, the human uptake and health consequences arising therefrom, can be grouped into four main areas – the reliability of the assumptions and analysis in each of these areas will be examined by a series of sample scenarios for the Beznau MOX delivery.

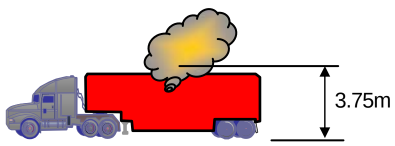
The essential geometry of the vehicle trailer containing the MOX fuel flasks is of the equivalent dimensions:-



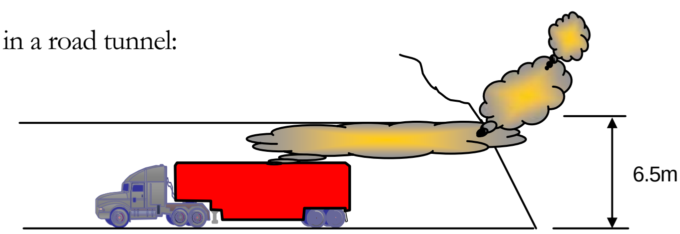
a) **Incident Scenarios:** Obviously, it is not possible to define or foresee exact scenarios but it is reasonable to include for both accidents and terrorist acts. These might range from, say, a terrorist attack directly targeting the flask(s) with an amour penetrating round whilst the flask is in the open, followed by a vehicle fire; a vehicle bomb alongside the SIFA trailer; a severe impact in a road tunnel followed by a fire; and, similarly an explosive event followed by a severe fire in the confines of a tunnel, and a host of other accident and terrorist attack scenarios.[24]

So far as modelling a range of release scenarios and the dispersion of the escaping radioactive plume the release height is determined by the the particular scenario, being:

i) in the open:



ii) on a ship deck or in a road tunnel:



For all terrorist act scenarios the MOX flasks and SIFA container are set to fail from the onset and for accidents involving severe fires the flasks fail in one hour.

The maximum credible release permitted under the IAEA regulations will included as a benchmark:[123]

SCENARIO	CONDITIONS	SOURCE DEFINITION	EFFECTIVE RELEASE HEIGHT	RELEASE DURATION
R_{REF}	IAEA A2 released over period of 1 week	point	3.75m	1 week
R1	Severe impact followed by 3 hour fire - flasks fail at 1 hour	dispersed	3.75m	60 minutes delay then 180 minutes
R2	Explosive Event in Open	dispersed	3.75	3 minutes
R3	Explosive Event in Tunnel/Ship Hold followed by 2 hour fire – flasks fail at onset	dispersed	6.5	600 minutes

b) **Release Fraction:** Those factors and conditions determining the quantity and extent of the radioactive release include, obviously, the robustness of the fuel pin sheathing design, the friability of the fuel pellets, the robustness and surety of the flasks and the transporting trailer. Other than some unsubstantiated claims[80] by the fuel manufacturer, BNFL, nothing is publicly available on the performance of MOX fuel when subject to abnormal conditions so, in this aspect, some extrapolation has been made to uranium oxide fuel which is very similar in make-up to MOX.

The energy lofting the releasing plume for scenarios involving fires is based on a proportion of the total energy of the fuel cargo carried two road petroleum tankers nominated to be involved in the incident (or the equivalent of a ship fire). For the explosive event in the open, the plume lofting energy is derived from the explosion and from the energy of the SIFA and its accompanying vehicles being on fire.

Adapting and using previous data for uranium oxide and surrogate fuel and assuming 4 fuel elements involved at an average plutonium content for the Beznau range of MOX, together with the conditions outlined above:

SCENARIO	CONDITIONS	ATMOSPHERIC FRACTIONAL RELEASE g per g fuel (U/Pu)	PLUME RISE ENERGY MW
R_{REF}	No external heating	IAEA A2 amount	0
R1	Impact damages fuel, ~0.5% of dispersible size, 20% of which is respirable sized – plume energy from burning vehicles	1 E-3 (5 E-3)	1
R2	Explosive Event in Open	6 E-5 & 8 E-4	2

R3	~10% of dispersible size, 20% of which is respirable sized – Phase 2 assumes one-fifth of 2 hydrocarbon road tankers directed into heating the escaping plume	1E-1 (2 E-2)	20

iii) **Dispersion:** There are a number of computer software program available for forecasting the dispersion and deposition of a radioactive release – for these examples the European Commission COSYMA program gives dispersion and deposition under specified climatic conditions using cyclic sampling of data previously acquired for specific locations in Europe – for these models the data obtained in Germany is adopted:

SCENARIO	PASQUILL CATEGORY	WIND SPEED m/s	PLUME SIGMAS	RELEASE PHASES	TERRAIN
R_{REF}	Assumes and models for a range of weather stability condition taken from weather measurements in Germany				Rough Rl=30cm
R1	ditto				rough
R2	ditto				rough
R3	ditto				rough

iv) **Dose Detriment:** The interaction of the released radioactivity with humans with these factors determining the human health detriment in the short, interim and long terms and such that might be carried across generations. These determinates include the route and efficacy of human uptake, the length of exposure within the contaminated area, the susceptibility of that individual to disease from the particular source, and the effectiveness of countermeasures introduced in the aftermath of the incident.

COSYMA includes a data base of point by point populations and agricultural produce (base on 100 km^2 comprising segments of constant 15^o longitude with a variable latitude to maintain equal areas) so a sample number of locations (ie Workington port and general area of the Beznau power plant) have been included in the analysis as example of the health detriment numbers for urban populations, although the population data has not been refined down below the 100km^2 cell size held by COSYMA. The local population refinement could be incorporated providing that the population distribution data is available for both of these sample and any other location nominated for analysis.

SCENARIO	CONDITIONS	POPULATION DENSITY per km^2	COUNTER MEASURES	COMMENTS
R_{REF}	Assumes neutral overcast day or night	Workington Port & Beznau Area	Shelter + evacuation	Population data not refined below 100km^2 grid
R1	ditto	ditto	ditto	ditto
R2	ditto	ditto	ditto	ditto
R3	ditto	ditto	ditto	ditto

Sheltering and evacuation countermeasures are invoked on a dose basis applied over a single region and at an effective dose of 0.05Sv[124] for evacuation but countermeasures based on purely geometric locations (ie automatic emergency planning zones) are not assumed because these generally automatic arrangements can only apply to a fixed nuclear installation. An initial delay of 3 hours from the onset of the incident is assumed before any countermeasures are effectively implemented and prior to evacuation 3 hours of sheltering is assumed. The time taken to move evacuees out of the area is 60 minutes and a further period of 6 hours is assumed before skin contamination can be removed from evacuees. For extreme releases and based on inhalation and resuspension dose allocation, relocation from the area is assumed to be completed within 5 days. For all periods of exposure (sheltering and transport out) normally accepted shielding factors are adopted.

In completing dispersion and consequence analysis the usual approach is to order a number of subsets of conditions and circumstances and rank these in order of probability of occurrence. The consequences of a given release will vary with the release location, the wind direction and the meteorological conditions. The wind direction determines which population may be exposed and the area of land which may be contaminated; the meteorological conditions influence the rate at which the (radio)activity disperses and thus the exposure of the population and the levels of contamination. For any location there will be a statistical distribution of both wind direction and meteorological conditions resulting in a probability distribution of consequences associated with any release scenario – this probability can be expressed in terms of its mean, median and percentiles.[125] The risk to any individual (the individual risk) is also a function of the distance and direction for the site of the release

This approach is applicable to *a priori* accidents (ie road traffic accidents) and the occurrence of natural hazards (ie earthquakes) with the probability of the accident occurring included in the overall probability train. Since the flask and transport system can be designed to withstand reasonably foreseeable accident circumstances and severities (so far as the IAEA testing regime applies), it follows that the probability of a flask damaging accident occurring will be low. This probabilistic approach can also be applied for radioactive releases that stem from terrorist attack, although the probabilistic train of reasoning excludes the terrorist event itself so.

OUTCOME OF THE SAMPLE ANALYSIS

The results for the sample analyses are given in Appendix V. Risk analysis is completed for the Workington Port and Beznau population distributions and note that the probabilities giving the mean risk of mortality do not include the fundamental probability of the incident itself occurring (ie the mortality probability is based entirely post-incident events and circumstances).

R_{REF} - IAEA LEAKAGE (OVER 1 WEEK)

The IAEA reference releases for Workington Port and Beznau result in very low (indiscernible) long term health consequences and no requirement for either short or long term countermeasures to be implemented, other than in the immediate vicinity of the incident in which convoy personnel would require immediate respiratory protection. To put such a release into the perspective of individual risk of mortality an individual located at 1km for the centre of the incident would incur an additional lifetime risk of about one in one hundred million (Graph 1 – Appendix V).

R1-3 ACCIDENT/INCIDENT RELEASES

On its part, the nuclear industry claims that the IAEA compliance tests render the flasks 'failsafe' but for these analyses the underlying assumption is that at an early stage in the accident/incident sequence the flask and SIFA vehicle containment fail permitting release of various fractions of the fuel content. This assumption is justified by referring to experiments and trials of Type B flasks and/or by adopting conditions (particularly the temperature and duration of fire) that have occurred in past accidents (tunnels and ship fires) and which would severely test and compromise the containment of the flask (including terrorist attack).

The pattern and extent of the dispersion of the radioactive release from the flask and the SIFA vehicle is much determined by the heat input to the plume – the dispersion pattern is reflected in the relocation patterns (here these are represented by a linear grid although the actual area coverage is radial or arc-like, with the area of each segment increasing proportionately with the radius). For all scenarios the implementation of sheltering and evacuation countermeasures is assumed to be timely and effective.

The **R2** explosive event (a short duration puff-like release) results in a limited dispersion with the health impact being relatively insignificant from the short term (7 day) radiation dose, resulting in individual mortality risk over the long term (50 years). Under the UK emergency planning requirements[58] the declaration of a 'Radiological Emergency' would not be triggered (5mSv exposure over one year), other than in the few hundred or so meters in the immediate locality of the incident. The long term (mean) risk of mortality is low at about 5.10-4 (one in ~2000) for an individual positioned at 1km from the incident centre. Since the near field population data has not been entered for either of the sample localities of Beznau or Workington the projected late mortality forecasts should be considered as indicative only.

Although the extent of the R2 release is considered to be somewhat limited here because it is assumed that the condensible vapours and aerosols escape through a relatively small breach area, thus there is some time during which particles and condensible vapors can deposit onto cask interior surfaces. On the other hand, when the flask breach/leakage area is large, the rapid flow of gases out of the flask carries most materials released from failed rods out to the environment before they can deposit onto cask interior surfaces.

For **R1** and on that assumption that the fuel cladding is severely damaged during the impact (although note that the previous work relied upon[105] does not provide much detail of this) the long term health implication extend to 3km or more if a long term individual mortality risk of one in 1000 is accepted as tolerable under such circumstances. For **R3** the radiological impact is significant out to distances exceeding 20km, with countermeasures in the short term being necessary out to 30 or so km. Again noting the reservations about the lack of near field population data, the probabilities of late mortality for the two sampled sites are given in the tabulations with the arithmetic mean being given at the 50th percentiles.

In Summary: The radiological significance of a range of incidents resulting in radioactive release from a consignment of 4 MOX fuel assemblies has been evaluated on the assumption that countermeasures will be implemented in a timely and effective manner. None of the scenarios results in short term acute doses in areas beyond the immediate locality of the incident with the health impact likely to develop in the longer term. Because the population data in the near field has not been included (with the population density being represented in 100 square kilometre blocks), the locality-specific analysis, such as the projected long term mortality rates.

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APPENDIX I

REACTOR AND FUEL ASSEMBLY DETAILS

APPENDIX II

FS65 – B(U)F-96 TRANSPORTATION FLASK

APPENDIX III

ROAD TRANSPORT VEHICLE AND TRAILER

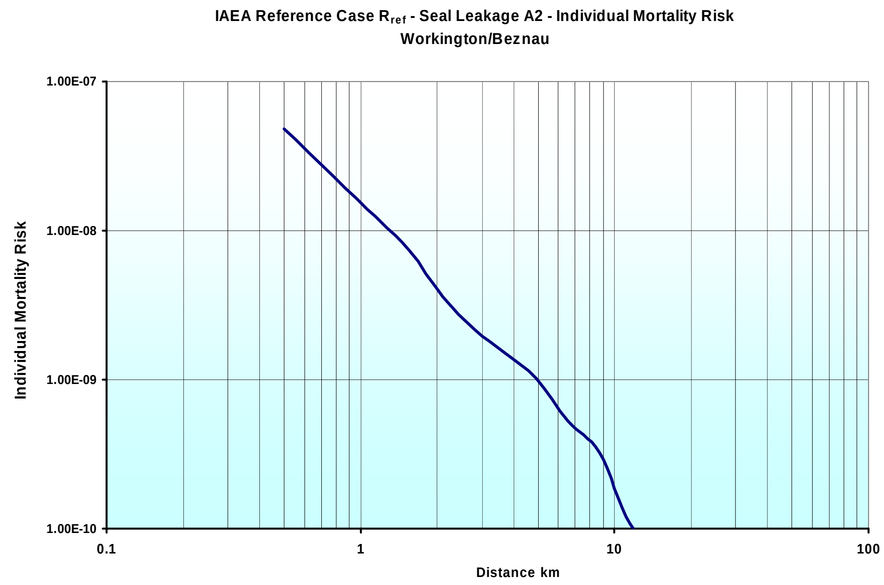
APPENDIX IV

COPY CORRESPONDENCE WIT H THE REGULATOR

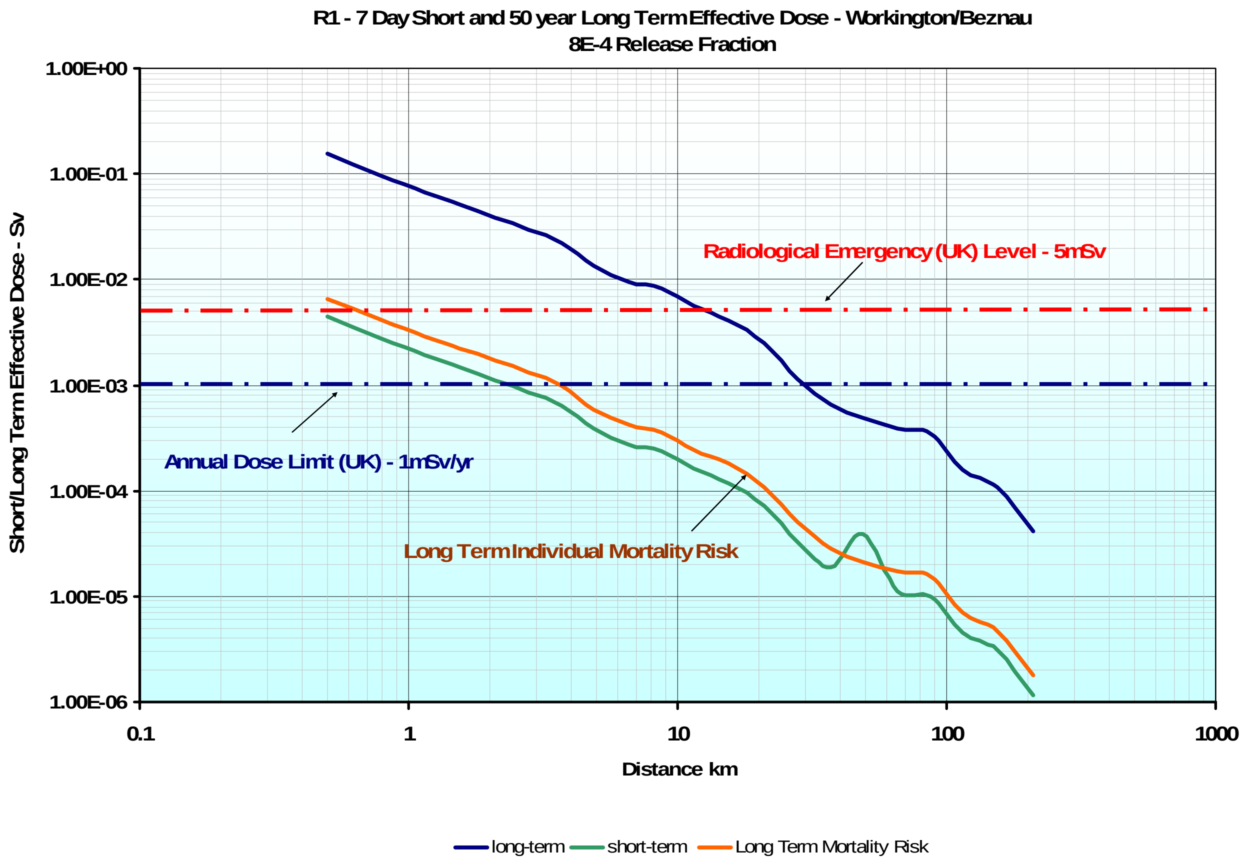
APPENDIX V

OUTLINE RESULTS OF THE SAMPLE ANALYSIS

R_{REF} - IAEA REFERENCE CASE – A2 SEAL LEAKAGE



R1 – SEVERE IMPACT FOLLOWED BY FIRE



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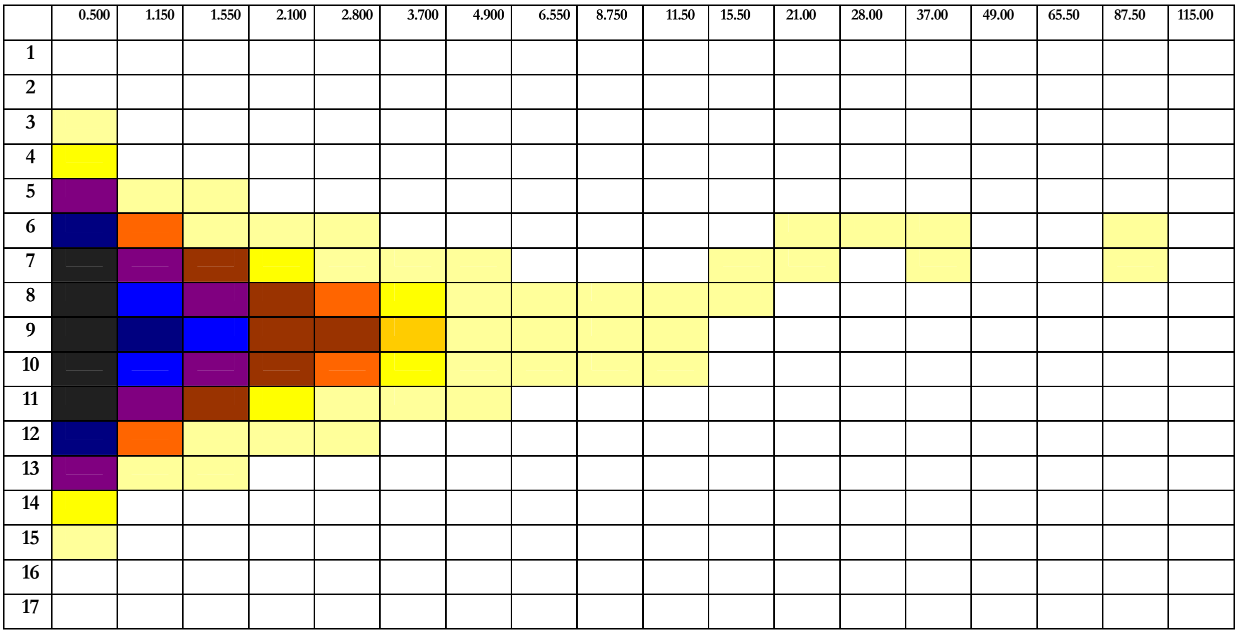

R1 - PATTERN OF RELOCATION BY SECTOR - WORKINGTON/BEZNAU & ENVIRONS

KEY	7 days	30 days	3 months	6 months	2 years	10 years	20 years	30 years	70+ years

	TOTAL	BONE MARROW	BONE SURFACE
MAXIMUM	1.591E+2	2.112E+1	1.526E+1
MEAN	7.828E+1	1.040E+1	7.511E+0
99TH PERCENTILE	1.591E+2	2.112E+1	1.562E+1
50TH PERCENTILE	8.128E+1	1.072E+1	7.762E+0

R1 – PROBABILITIES OF LATE MORTALITY - WORKINGTON & ENVIRONS

	TOTAL	BONE MARROW	BONE SURFACE
MAXIMUM	9.020E+2	1.202E+2	8.683E+1
MEAN	4.158E+2	5.535E+1	3.999E+1
99TH PERCENTILE	9.020E+2	1.202E+2	8.683E+1
50TH PERCENTILE	4.467E+2	6.026E+1	4.266E+1

R1 – PROBABILITIES OF LATE MORTALITY - BEZNAU & ENVIRONS

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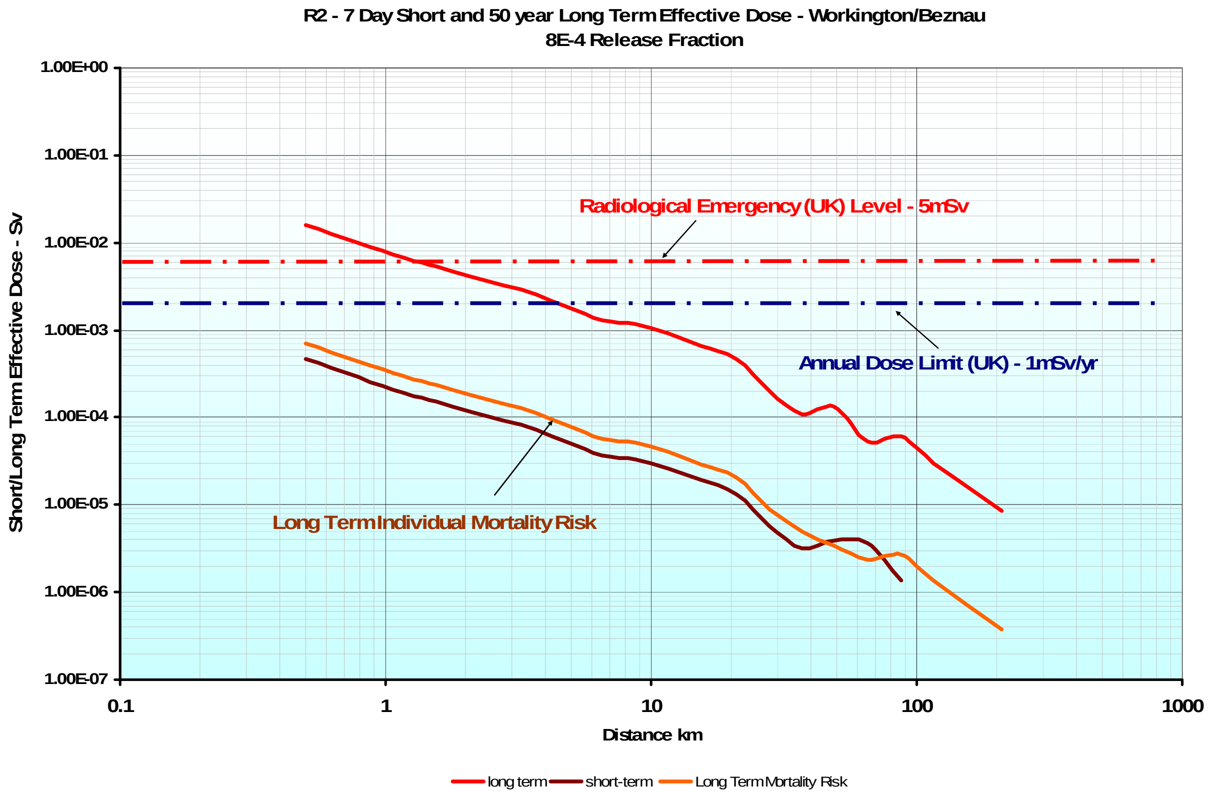
R2 – Explosive Event in the Open



	0.500	1.150	1.550	2.100	2.800	3.700	4.900	6.550
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R2 - Pattern of Relocation by Sector - Workington/Beznau & Environs

KEY	7 days	30 days	3 months	6 months	2 years	10 years	20 years	30 years	70+ years

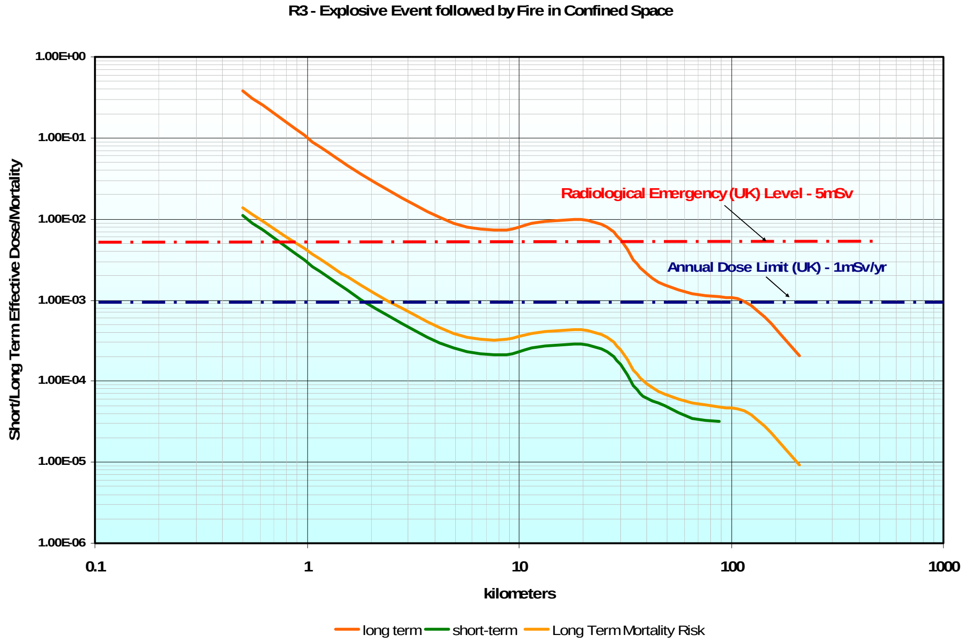
	TOTAL	BONE MARROW	BONE SURFACE
MAXIMUM	3.2731E+1	4.346E+0	3.140E+0
MEAN	1.297E+1	1.722E+0	1.244E+0
99TH PERCENTILE	3.273E+1	4.346E+0	3.140E+0
50TH PERCENTILE	1.349E+1	1.778E+0	1.288E+0

R2 – PROBABILITIES OF LATE MORTALITY - WORKINGTON & ENVIRONS

	TOTAL	BONE MARROW	BONE SURFACE
MAXIMUM	2.828E+3	3.807E+2	2.751E+2
MEAN	1.309E+3	1.745E+2	1.261E+2
99TH PERCENTILE	2.828E+3	3.807E+2	2.751E+2
50TH PERCENTILE	1.175E+1	1.585E+2	1.148E+1

R2 – PROBABILITIES OF LATE MORTALITY - BEZNAU & ENVIRONS

R3 – EXPLOSIVE EVENT AND FIRE IN CONFINED AREA (TUNNEL/SHIP HOLD)



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	0.500	1.150	1.550	2.100	2.800	3.700	4.900	6.550	8.750	11.50	15.50	21.00	28.00	37.00	49.00
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R3 - Pattern of Short Term Countermeasures – Sheltering & Evacuation by Sector - Workington/Beznau & Environs

	0.500	1.150	1.550	2.100	2.800	3.700	4.900	6.550	8.750	11.50	15.50	21.00	28.00	37.00
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R3 - Pattern of Long Term Relocation by Sector - Workington/Beznau & Environs

KEY	7 days	30 days	3 months	6 months	2 years	10 years	20 years	30 years	70+ years

	TOTAL	BONE MARROW	BONE SURFACE
MAXIMUM	1.169E+3	1.553E+2	1.122E+2
MEAN	3.085E+2	4.095E+1	2.959E+1
99TH PERCENTILE	1.169E+3	1.553E+2	1.122E+2
50TH PERCENTILE	2.291E+2	3.090E+1	2.239E+0

R3 – PROBABILITIES OF LATE MORTALITY - WORKINGTON & ENVIRONS

	TOTAL	BONE MARROW	BONE SURFACE
MAXIMUM	1.565E+2	2.078E+1	1.502E+1
MEAN	6.899E+1	9.161E+0	6.619E+1
99TH PERCENTILE	1.565E+2	2.078E+1	1.502E+1
50TH PERCENTILE	7.079E+1	9.333E+0	6.761E+1

R3 – PROBABILITIES OF LATE MORTALITY - BEZNAU & ENVIRONS

APPENDIX VI

REFERENCES NOT CITED IN MAIN TEXT

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AUTHOR	TITLE	LOCATION	ABSTRACT
Charles J, Konirsch 0	*Transportation by Road of Plutonium as a Reusable Product*	*Proc 11th Inte Conference on the Packaging and Transportation of Radioactive Materials (PATRAM '95) (December 3-8, 1995, Las Vegas, Nevada), p. 777.*	
Seehars H, Hochrainer D	*'Durchführung von Experimenten zur Unterstutzung der Annahmen zur Freisetzung von Plutonium bei einem Flugzeugabsturz*	*Fraunhofer-Institute, SR 0205A, March 1982*	
Sprung J L et al	*Data and Methods for Assessment of the Risks Associated with the Maritime Transport of Radioactive Materials Results of the Sea RAM Program Studies*	*SANDIA Report SAND98-1171/1, 1998*	
D Tsumune et al	*Study on Transport Safety of Fresh MOX Fuel – Radiation Dose from Package Hypothetically Submerged into Sea*	*CRIEPI, EU98003, July 1999*	
0 Kato, T Saegusa	*High Temperature Performance Limit of Containment System of Transport Flask,*	*CRIEPI, U97101, 1998*	*In Japanese*
Sugaya et al	*The Measurement of Leaching velocity of Pu in MOX fuel into Seawater*	*Atomic Energy Society of Japan, Summaries of the Fall Meeting, 1996*	*In Japanese*
Science and Technology Agency	*Demonstration Test on Safety of Plutonium Package*		*In Japanese*
C Itoh	*Study on Transport Safety of Fresh MOX Fuel*		
J. Kurakami, Y. Ouchi and M. Usami	*Transport of Fresh MOX Fuel Assemblies for MONJU Initial Core*		*Transport of fresh MOX fuel assemblies for the prototype FBR MONJU initial core started in July 1992 and ended in March 1994. As many as 205 fresh MOX fuel assemblies (109 assemblies for an inner core, 91 assemblies for an outer core and 5 assemblies for testing) were transported in nine transport missions. The packaging for fuel assemblies, which has shielding and shock absorbing material inside, meets IAEA regulatory requirements for Type B(U) packaging including hypothetical accident conditions such as the 9 m drop test, fire test, etc. Moreover, this packaging design features such advanced technologies as high performance neutron shielding material and an automatic hold-down mechanism for the fuel assemblies. Every effort was made to carry out safe transport in conjunction with the cooperation of every competent organisation. This effort includes establishment of the transport control centre, communication training, and accompanying of the radiation monitoring expert. No transport accident occurred during the transport and all the transport missions were successfully completed on schedule*
Y. Rouquette and F. Potelle	*FS 65: A New Packaging for MOX Transport*	*Int. J. Radioact. Mat. Transp. 8(3-4), pp 253-255 (1997)*	This paper describes the background, development, testing and performance assessment of an optimised design for a new packaging for the transport of MOX fuel from COGEMA sites, including the associated interfacing equipment at the COGEMA and COGEMA partner sites. The overall project was completed within 20 months
J. Edwards, A. Hough, J.A.C. Marples and T. Ohe	*Leaching of Unirradiated MOX Fuel in Sea Water*	*Int. J. Radioact. Mat. Transp. 9(2), pp 147-156 (1998)*	MOX fuel, in the form of pellets or crushed powder, has been leached in sea water under various conditions to simulate and determine the potential effects of a transport accident leading to a breaching of the fuel cladding and subsequent attack by sea water. The simulation involved the immersion of MOX in sea water over a period of 11 months and measuring the leach rates by analysing the leachate water at intervals for Pu and Am and also, at the end of the tests, for U. The Pu and Am leach rates obtained were equivalent to a surface removal rate of ~0.3 æm per century for leachates adjusted to pH 4 and to less than 0.03 æm per century for samples leached at a more realistic pH 8. The Pu and Am concentrations in the leachates were probably limited by their solubilities and by sorbtion on the surrounding surfaces as would presumably occur in any real case.
D.J. Ammerman and J.S. Ludwigsen	*Crush Loadings to Radioactive Material Transport Packages During Ship Collisions*	*Int. J. Radioact. Mat. Transp. 9(2), pp 141-145 (1998)*	Accident-resistant Type B packages are used to transport radioactive materials such as spent fuel and vitrified high level waste in all surface modes, in accordance with national and international regulations. As with other modes, a sea-going conveyance (vessel) carrying radioactive material (RAM) may be involved in a collision accident. If the vessel is struck by another commercial vessel with sufficient tonnage and velocity, the RAM package may be impacted by the penetrating bow of the striking ship. The impact on the RAM package by the bow is less damaging to the package than the regulatory 9 m drop test. This is because the velocity is always lower and the bow always less rigid than the essentially unyielding target required for the drop test. Thus, the only remaining mechanism for gross damage to the package is crush loading. For the package to be crushed, forces must act on two opposing sides. In this paper, the bow of the impacting ship is assumed to be able to impart an infinite

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			force to one side of the package. The opposing force is supplied by the hull of the struck ship on the side away from the collision. Resistance of this hull to penetration by the package determines the maximum magnitude of the crush force. Work described in this paper is aimed at determining an upper bound for this force.
D. Raffestin, F. Armingaud, T. Schneider and S. Delaigue	*Statistical Analysis of Accident Data Associated with Sea Transport*	*Int. J. Radioact. Mat. Transp. 9(2), pp 103-109 (1998)*	This analysis, based on Lloyd's database, gives an accurate description of the world fleet and the most severe ship accidents, as well as the frequencies of accident per ship type, accident category and age category. Complementary analyses were achieved using fire accident databases from AEA Technology and the French Bureau Veritas. The results should be used in the perspective of safety assessments of maritime shipments of radioactive material. For this purpose the existence of the regulations of the International Maritime Organisation has to be considered, leading to the introduction of correction factors to these statistical data derived from general cargo-carrying ships.
N. Watabe, H. Suzuki, Y. Nishimura, H. Mori and Y. Kouno	*An Estimation Method of Marine Accident Probability for Exclusive-Use Ships*	*Int. J. Radioact. Mat. Transp. 9(2), pp 111-121 (1998)*	The results of probabilistic evaluation of marine accidents to ships dedicated exclusively for sea transport of radioactive materials are described. The scenario analysis is executed first. Fire accidents including engine room fire and sea fire and sinking accidents caused by collision or stormy weather are considered as 'hypothetical accidents'. Some consideration of protection methods is additionally made. Secondly, exclusive-use and ordinary 3000-5000 GT class cargo ships, which are of equal size and tonnage, are selected for comparison, and the probabilities of the above hypothetical accidents are estimated from the casualty statistics of Japan. Thirdly, the probability of 'total loss' of ordinary cargo ships and the exclusive-use ships are calculated and compared by a method developed by the Shipbuilding Research Association of Japan (JSRA). Finally, the maritime accident probabilities, considering the protection methods for exclusive-use ships, are estimated. It should be noted that these probabilities do not express the probability of breaching the packaging.
P. Purcell	*The Development of a Package for the Transport of New Mixed Oxide Fuel Assemblies within Europe*	*Int. J. Radioact. Mat. Transp. 10(2), pp 85-90 (1999)*	The use of mixed oxide (MOX) fuels in commercial reactors has increased significantly over the past 10 years as an effective way of using stocks of plutonium produced from reprocessing uranium fuels. Now, with advances in fuel design MOX can give performance approaching that of enriched uranium fuel. To meet demand from European and Japanese utilities, British Nuclear Fuels are currently building a large scale plant at Sellafield to assemble MOX fuels. This required a new transport package to be developed capable of carrying high specification fuels to customers in Europe whilst complying with the latest 1996 IAEA ST-1 Transport Regulations. This package is known as Euromox and currently under development to enter service in 2003. Relatively few packages exist for the transport of MOX fuels and Euromox is the first designed by BNFL for shipments to Europe. Euromox has provided several technical challenges in its development arguably exceeding those typically encountered during the development of new packages for irradiated fuel transports.
J.S. Hughes, C. Ringot and K.B. Shaw	*Development of an Event Severity Scale for Transport Accidents and Incidents*	*Int. J. Radioact. Mat. Transp. 10(3), pp 147-154 (1999)*	Many millions of packages of radioactive materials are transported safely each year throughout the world. Most of these materials are for medical and general industrial use. Accidents and incidents do occur during transport although any consequences are normally limited by the built-in safety features of the package together with the controls required for transport, including emergency response procedures. Criteria, based on the International Nuclear Event Scale, have been developed for transport events taking account of package type, location of the event, atmospheric releases, and exposures. Some examples of past events are given. Degradation of defence in depth is found in most transport events. In order to be able to communicate the significance of a transport event it is recommended that the International Nuclear Event Scale be expanded to encompass more broadly all types of transport operations involving radioactive materials
C.N. Young	*Report on the Adoption of the IMO 'Code for the Safe Carriage of Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes in*	*Int. J. Radioact. Mat. Transp. 6(1), pp 11-17 (1995)*	The background and development of the International Maritime Organisation's *Code for the Safe Carriage of Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes in Flasks on board Ships* (INF

	Flasks on Board Ships'		Codes) is described. The INF Code was adopted in November 1993 by the IMO Assembly as a voluntary code of practice, following the detailed considerations and proposals of two joint IMO/IAEA/UNEP working group meetings. The paper describes the plans to implement the Code in the UK and the actions being taken by the nuclear industry to comply with it. The full text of Assembly Resolution A.748(18) and the INF Code is given.
M. Carr and S.D. York	*Plutonium Transport: Past, Present and Future*	*Int. J. Radioact. Mat. Transp. 4(2), pp 139-144 (1993)*	The transport of radioactive materials dates back to the beginning of the nuclear industry. The development of nuclear plants and the international trade in fuel cycle services has led to a transport infrastructure to service the industry. Advances in radioactive material package design and technology have been led by increasing emphasis on safety assurance and compliance with transport regulations which in many cases exceed those applied to other dangerous goods. In the case of certain materials security during transport it has equal emphasis with safety, and plutonium, in its many forms, attracts the most onerous security requirements during transport. BNFL has safely and efficiently transported plutonium both nationally and internationally for 30 years. The Company is committed to the continuation of maintaining such transport in a safe, secure and cost effective manner.
T. Kondo	*Safe Transport of Radioactive Materials in Japan*	*Int. J. Radioact. Mat. Transp. 9(1), pp 47-51 (1998)*	This is an outline of Japan's safety regulation system for the transport of radioactive materials, including the procedures application and approval for transport and emergency preparedness, with emphasis on the transport of nuclear fuel materials.
N. Watabe, Y. Kohno, D. Tsumune, T. Saegusa and H. Ohnuma	*An Environmental Impact Assessment for Sea Transport of High-Level Radioactive Waste*	*Int. J. Radioact. Mat. Transp. 7(2-3), pp 117-127 (1996)*	This work was carried out to study the safety evaluation in a hypothetical submergence accident onto the seabed, prior to the international maritime transport between Europe and Japan in 1995. In this study, inadmissibly conservative assumptions were omitted in order to construct adequate accident scenarios from the engineering aspect. Input data of source terms of high level vitrified wastes, various flow coefficients in the sea, and other factors were thoroughly examined and, finally, a new concept of a solution method for radioactive nuclides concentration was proposed with regard to oceanography.
H. Hesse	*The Transport of Radioactive Materials by Sea - Role of the IMO*	*Int. J. Radioact. Mat. Transp. 7(4), pp 295-297 (1996)*	The INF Code was adopted by IMO Assembly Resolution A.748(18) in November 1993 as a voluntary code of practice for application by IMO Member States. This article describes briefly the activities of IMO relating to the carriage of dangerous goods by sea; including radioactive materials and, in particular, the work leading to the adoption of the INF Code and the latest developments in the IMO in relation thereto.
HMSO	*Mixed Oxide Nuclear Fuel (MOX)*	*Post 137, April 2000 House of Commons Library*	
Paul Leventhal	*Overview of Ultra Hazardous Cargo by Sea*	*(Malaysia Conference October 1999*	
Shaun Burnie and Damon Moglen	*The Shipment of Ultrahazardous Radioactive Cargo: Japan's Plutonium Program, Its Threat to En-route Nations and Options for Action*	*(Malaysia Conference October 1999*	
Tadao Ishibashi	*Japanese Perspective/Policy on Ultra Hazardous Cargo*	*(Malaysia Conference October 1999*	
Edwin S. Lyman	*The Sea Shipment of Radioactive Materials: Safety and Environmental Concerns*	*(Malaysia Conference October 1999*	
Ronald B. Pope & Xavier Bernard-Bruls	*Monitoring High Activity Radioactive Material Transport by Sea – Accident Scenarios and Predicted Responses*	*(Malaysia Conference October 1999*	
H.Hesse	*IMO Requirements Relating to maritime Transport of Hazardous Materials in General and Nuclear Materials in Particular - Development, Current Status & Future Activities*	*(Malaysia Conference October 1999*	
Professor Jon M. Van Dyke	*The Legal Regime Governing Sea Transport of Ultra Hazardous Radioactive Materials, With Proposals for Action*	*(Malaysia Conference October 1999*	
H P Dyck, R Rawl, L Van Den Durpel	*The Transportation of PuO2 and MOX fuel and management of irradiated MOX fuel*	*IAEA-SM-358/34, Proc MOX Fuel Cycle Technologies for Medium and Long Term Deployment, Symp*	

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		May 1999, Vienna	
A Verdier	*MoOX Fuel Transport: The French Experience*	*IAEA-SM-358/35, Proc MOX Fuel Cycle Technologies for Medium and Long Term Deployment, Symp May 1999, Vienna*	
IAEA-TECDOC-766	*Safe Handling, Transport and Storage of Plutonium*	*IAEA, October 1994*	
	Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (1985 Edition) -- Third Edition (As Amended 1990): A Safety Guide	*Safety Series No. 37*	This publication is an updated version of the Third Edition of the Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (1985 Edition) and replaces all previous publications of Safety Series No. 37. It includes the changes to Safety Series No. 37 contained in Supplement 1988 to the Regulations for the Safe Transport of Radioactive Material as well as some modifications adopted by a Review Panel convened in Vienna in July 1989. *Contents:* Section I. Introduction; Section II. General provisions; Section III. Activity and fissile material limits; Section IV. Preparation, requirements and controls for shipment and for storage in transit; Section V. Requirements for radioactive materials and for packagings and packages; Section VI. Test procedures; Section VII. Approval and administrative requirements; Appendix I: List of regulatory documents of international and regional international organizations; Appendix II: Contamination control; Appendix III: Half-life and specific activity of radionuclides, and specific activity of uranium and thorium; Appendix IV: Quality assurance in the safe transport of radioactive material; Appendix V: Guide for quality assurance programme; Appendix VI: Example calculations for establishing minimum segregation distance requirements; Appendix VII: Acceleration values and calculation methods for package tie-down forces; Appendix VIII: Example of a radiation protection programme for exclusive use vessels; Appendix IX: Influence of brittle fracture on material integrity; Appendix X: Criticality safety assessments.
A. B. Rothman and Y. Y. Liu	*Review of DOE Criteria for Safe Storage of Pu Metals and Oxides*	Proc. Amer. Nucl. Soc. 3rd Top. Mtg. on DOE Spent Nuclear Fuel and Fissile Matls., Charleston, SC, September 8-11, 1998	
J. R. Liaw and Y. Y. Liu	*Criticality Control in Shipments of Fissile Materials*	Proc. Topical Mtg. on DOE Spent Nuclear Fuel and Fissile Material Management, San Diego, June 4-8, 2000	
Frank Nitsche, Christel Fasten	*Transport Regulations for Radioactive Material in Germany*	Federal Office for Radiation Protection, Germany	
Didier Brochard, Bruno Autrusson, Franck Delmaire-Sizes, Alain Nicaud	*Behavior of Transport Casks Under Explosive Loading*	Institut de Protection et de Sûreté Nucléaire;	
F. Gil,	*International Initiatives in Transportation Sabotage Investigations*	CS Communications et Systems Group	
Richard Yoshimura, Manuel Vigil,	*Spent Fuel Cask Sabotage Investigations*	SNL	
Florentin Lange, Gunter Pretzsch, Gesellschaft für Anlagen	*Experiments to Quantify Potential Releases and Consequences from Sabotage Attack on Spent Fuel Casks*	Fraunhofer Institute for Toxicology and Aerosol Research	
Robert Halstead	*Nuclear Waste Transportation Terrorism and Sabotage: Critical Issues*	State of Nevada, Agency for Nuclear Projects; James David Ballard, Grand Valley State University, School of Criminal Justice	
Fred Dilger	*ANF-18: A New Transport Container for Fresh PWR Fuel Assemblies According to IAEA Requirements*	Nuclear Waste Division, Clark County, Nevada	
Joseph Nichols III, Kirk Brownell	*Critical Design Challenges of the MOX Fresh Fuel Package (MFFP*	Packaging Technology, Inc.	

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Gerry Holden, Garry Hall	*Development of a Type C Package for AWE*	Gravatom Engineering Systems Ltd;, AWE Ltd.	
Christophe Mattera, Badèa Martinotti,	*Consequences of the Use of Average Pu-Enrichment for Criticality Studies of PWR MOX-Fuel Transport Packages*	Transnucléaire; Hervé Issard, COGEMA Inc	
I.R. Porter and M. Carr	Transport of MOX Fuel	Int. J. Radioact. Mat. Transp. 8(3-4), pp 361-364 (1997)	
Y. Miura, Y. Ouchi, J. Kurakami and M. Usami	Transport of Fresh MOX Fuel Assemblies for the MONJU Initial Core	Int. J. Radioact. Mat. Transp. 11(3), pp 239-253 (2000)	
D. Tsumune, H. Suzuki, T. Saegusa, K. Maruyama, C. Ito and N. Watabe	Estimated Radiation Dose from a MOX Fuel Shipping Package that is Hypothetically Submerged in the Sea	Int. J. Radioact. Mat. Transp. 11(3), pp 261-265 (2000)	By assuming that a fresh MOX fuel package might be sunk from some unexpected cause. In both cases, for a package sunk in the coastal region and for one sunk in the open sea, the evaluated results of the dose equivalent by radiation exposure of the public are far below the dose equivalent limit of the ICRP recommendation (1 $mSv.y^{-1}$).
R.E. Luna	Comparison of Results from Two Spent Fuel Sabotage Source Term Experiments	Int. J. Radioact. Mat. Transp. 11(1-2), pp 81-84 (2000)	
Y. Brachet and T. Lallemand	MOX Packaging: Experience and Development	Int. J. Radioact. Mat. Transp. 11(1-2), pp 101-108 (2000)	
D.J. Ammerman and J.S. Ludwigsen	Crush Loadings to Radioactive Material Transport Packages During Ship Collisions		
J. Edwards, A. Hough, J.A.C. Marples and T. Ohe	*Leaching of Unirradiated MOX Fuel in Sea Water*	*International Symposium on Mox Fuel Cycle Technologies for Medium and Long-Term Deployment Vienna, Austria 17 - 21 May 1999*	MOX fuel, in the form of pellets or crushed powder, has been leached in sea water under various conditions to simulate and determine the potential effects of a transport accident leading to a breaching of the fuel cladding and subsequent attack by sea water. The simulation involved the immersion of MOX in sea water over a period of 11 months and measuring the leach rates by analysing the leachate water at intervals for Pu and Am and also, at the end of the tests, for U. The Pu and Am leach rates obtained were equivalent to a surface removal rate of ~0.3 µm per century for leachates adjusted to pH 4 and to less than 0.03 µm per century for samples leached at a more realistic pH 8. The Pu and Am concentrations in the leachates were probably limited by their solubilities and by sorbtion on the surrounding surfaces as would presumably occur in any real case
	Canadian Transportation Plan for the PARALLEX Project-Los Alamos to Chalk River Shipment	*AECL, , 100-37000-TD-003, Rev. 0, 1999 August,*	
Nuclear Control Institute	*The Facts About Air Transport of Mixed-Oxide Fuel*	*June 20, 1997 web reference: http://www.nci.org/pr62097.htm*	
Sharon Tanzer	*Status Report on Air Shipments of Plutonium*	*http://www.nci.org/ib82896.htm*	
R. J. Halstead	*State of Nevada Studies of Potential Terrorism and Sabotage Against Spent Fuel Shipments*		
R. E. Luna , H. R Yoshimura, M. G. Vigil, F. Lange, G. Pretzch, W. Koch and M. Hoover	*Perspectives on Spent Fuel Cask Sabotage*		There have been a number of experiments relating to sabotage of radioactive material transport containers. Most of the experiments deal with spent fuel casks because these shipments, if successfully sabotaged, have the potential to lead to significant radiological impacts. This potential is driven by the large amount of RAM contained (frequently in the range of 2 to 20 MCi for commercial power reactor fuel). However, producing a release from a spent fuel cask is a formidable task owing to the robust design necessitated by containment and shielding requirements. Projections of the potential releases and radiological impacts have been performed a number of times
Hodge, C. V. and J. E. Campbell	*Calculations of Radiological Consequences from Sabotage of Shipping Casks for Spent Fuel and High-Level Waste*	*NUREG-0194, 1977*	
Luna et al	Projected source Terms for Potential Sabotage Events Related to Spent Fuel	Sandia National Laboratories, Albuquerque, NM USA,	

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	Shipments	Report No. SAND99-0963, June 1999	
Pretzsch, G. and Lange	Radiological Consequences of Radioactivity Release from a Spent Fuel Transport Cask after Shaped Charge Attack	GRS-A-2158, May 1994	
Pretzsch, G. and Lange, F	Experimental Determination of UO2 Release from a Transport Cask for Spent Fuel Elements after Shaped Charge Attack	GRS-A-2157, May 1994	
Sandoval, et al	An Assessment of the Safety of Spent Fuel Transportation in Urban Environs	SAND82-2365, Sandia National Laboratories, Albuquerque, New Mexico, 1983	
Schmidt, et al	Shipping Cask Sabotage Source Term Investigation	NUREG/CR?2472, 1981	
Schmidt, et al	Final Report on Shipping Cask Sabotage Source Term Investigation	NUREG/CR2472 (BMI 2095) 1982	
Audin, L.,	Analyses of Cask Sabotage Involving Portable Explosives: A Critique,	Draft Report, Prepared for Nevada Agency for Nuclear Projects/Nuclear Waste Project Office, October, 1989	
Ballard, J.D.,	A Preliminary Study of Sabotage and Terrorism as Transportation Risk Factors,.	Draft Report Prepared for Nevada Agency for Nuclear Projects/Nuclear Waste Project Office, October, 1996	
Dietrich, A.M., and W.P. Walters	Review of High Explosive Device Testing Against Spent Fuel Shipping Casks	U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Prepared for U.S. Nuclear Regulatory Commission, October 13, 1983.	

1 Swiss nuclear power stations are:

SITE	PLANT	REACTOR TYPE	CONSTRUCTION START	GRID CONNECTION	SHUT DOWN
Beznau	**Beznau-1**	PWR 350	1965	1969	
	Beznau-2	PWR 350	1968	1971	
Goesgen	**Goesgen**	PWR 940	1973	1979	
Leibstadt	**Leibstadt**	BWR 1000	1974	1984	
Muehleberg	**Muehleberg**	BWR 320	1967	1971	

2 Both fission of isotopes such as uranium-235, and the formation of new, heavier isotopes due to neutron capture, primarily by U-238 occurs in the fuel mass of an operational nuclear reactor. The U-238 will partially convert to plutonium-239 and by successive neutron capture Pu-240, Pu-241 and Pu-242 as well as other transuranic or actinide isotopes. Pu-239 is fissile, like U-235, so it too undergoes fission and is progressively burnt-up in the reactor. With the fuel being removed from the reactor core every three years or so, most of the Pu-239 is "burned" in the reactor, behaving like U-235 with its fission releasing a similar amount of energy. The higher the burn-up, the less plutonium remains in the spent fuel, but typically about one percent of the spent fuel discharged from a reactor is plutonium, and some two thirds of the plutonium is Pu-239. Worldwide and if all of the fuel was reprocessed to chemically extract the plutonium, almost 100 tonnes of plutonium in spent fuel arises each year. The plutonium so extracted can be repackaged as nuclear fuel in the form of mixed oxide or MOX fuel. Recycled in this way and in gross terms and somewhat theoretically, a single recycle of plutonium increases the energy derived from the original uranium by some 12%, and if the uranium is also recycled this becomes about 20%.

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MOX was first used in a thermal reactor in 1963, but did not come into wider use until the 1980s. Today MOX is used in a number of reactors in Europe and is planned to be used in Japan. Currently over 30 reactors in Europe (Belgium, Switzerland, Germany and France) are licensed to use and are partially fuelled MOX and a further 20 have been licensed to do so. Japan also plans to use MOX in around a third of its reactors by 2010. Most reactors use it as about one third of their core, but some will accept up to 50% MOX assemblies. France aims to have all its 900 MWe series of reactors running with at least one third MOX. Japan aims to have one third of its reactors using MOX by 2010, and has approved construction of a new reactor with a complete fuel loading of MOX.

With persistently low uranium prices, reprocessing to separate plutonium for recycle as MOX is not itself economic but, the nuclear industry claims that coupled with reducing the volume of spent fuel to be managed, it can become so.

3 The district heat extraction system installed and commissioned at the Beznau Nuclear Power Plant 1983 and 1984. Together with a six kilometres extension in 1994, the system now consists of a 35 kilometres main network and 85 kilometres of local distribution pipelines. Around 2160 consumers of the Refuna district heating, small and large private buildings, industrial and agricultural enterprises are supplied with heat from the Beznau plant.

4 The Beznau power station is Westinghouse designed, constructed by the Westinghouse Brown-Boverie consortium with subsequent modifications to the plant being undertaken by Framatome in the late 1990s. The containment design of each reactor installation includes primary containment, the reactor pressure vessel, and its two steam generators, and a secondary steel lined, cylindrical concrete containment of 33m diameter by 59m height. Each reactor pressure vessel is 3.33m internal diameter by 10.24m high, carbon steel with a 4mm austenitic stainless steel lining, operating at 170bar pressure and about 340^{o}C. The reactor core receives 121 fuel assemblies, each of 3.5m length and made up of 179 fuel pins holding a stack of sintered pellets. The reactor fuel core is segregated in three levels of uranium enrichment.

5 Swiss electricity utilities signed reprocessing contracts with COGEMA and BNFL. The total amount of fuel to be reprocessed is between 1,000 and 1,100 tonnes of heavy metal which corresponds to about one third of the total quantity of fuel produced during forty years of operation of the five Swiss nuclear power plants. With the reprocessing contracts, Switzerland is entitled to a considerable amount of separated plutonium. The only use for this plutonium in Switzerland is to introduce it into mixed oxide fuel (MOX), containing both plutonium and uranium although it is doubtful that all of the plutonium scheduled to be returned will be sued in MOX fuel and the surplus plutonium will have to be stockpiled.

6 Ahead of NOK's fuel being reprocessed, the plutonium content of the MOX fuel was leased from other sources on a future swap and return basis – see Stratton R, *Experience in the Use of MOX Fuels in the Beznau Plants of NOK*, International Symposaium of MOX Fuel, Inst Nuclear Engineers, 1996

7 WISE - http://www.wise-paris.org/index.html?/english/ournewsletter/8/page2.html&/english/frame/menu.html&/english/frame/band.html

8 Shortly after startup following 1999 outage, increased values of activity were measured in the water of the primary circuit in *Unit 1*, indicating that fuel assembly defects had occurred. Subsequently, during the 2000 outage 4 defective assemblies were identified, originating from a delivery batch of 12 BNFL uranium/plutonium mixed oxide (MOX) fuel assemblies Two of these MOX assemblies had already become defective in 1997 and had been repaired. All fuel assemblies from the affected BNFL delivery batch were removed from the core.

9 Swiss Nuclear Inspectorate Year 2000 Report.

10 To date, more than 150 MOX assemblies loaded into both Beznau reactors. Due to slow build up of its own plutonium the Beznau operator, NOK, borrowed Pu from other parties, in this way it gained early experience in the use of MOX. The maximum assembly exposure is 43 GWIYt. The irradiated MOX fuel is stored in the reactor pools and it is not intended to send this fuel for reprocessing. In the case of dry interim storage the MOX fuel will be loaded into casks. Due to higher decay heat and neutron doses the number of MOX fuel assemblies per cask might be limited and a co-loading with uranium fuel might be necessary

11 According to Ref 7, the previous BNFL MOX consignment to Beznau was during 1997, when 4 MOX fuel assemblies were loaded. In total it is estimated that the number of MOX fuel assemblies since 1978 totals 120 assemblies so, on average, Beznau does not seem to have been operating at its full 40% licensed level for MOX. In comparison the first MOX loading of the Gösgen reactor, which is licensed for 30% MOX, comprised 8 MOX fuel assemblies out of 40 assemblies, corresponding to 20% of the core fuel load.

In total 28 MOX fuel assemblies were supplied to the Gösgen plant already during April and May 1997 from Belgonucléaire. The operator Kernkraftwerk Gösgen-Däniken AG has therefore stored the MOX fuel on-site. Apparently Belgonucléaire was not willing to store this MOX fuel before shipping it to Switzerland according to Gösgenâs refuelling schedule.

The Swiss submission to the IAEA of March 1998, states that *"more than 2.2 tonnes of plutonium"* in MOX fuel has been used in Swiss reactors – see Ref 7.

12 The *Arneb* was subsequently purchased by BNFL and renamed *Atlantic Osprey*. The *Atlantic Osprey*, was built in Hamburg in 1986, and has a gross tonnage of 3,640 tonnes, a length of 88.57m, and a speed of 13 knots and is classified by Lloyds Registry as 'ice strengthened' and class INF2 (Irradiated Nuclear Fuel Code). This will permit the carriage of irradiated fuel, high level nuclear waste and Category I MOX fuel. In February 2001, it underwent a Port State Control inspection at Hull where a number of deficiencies were found in a range of inspection categories, which included safety in general, fire safety measures and crew certification. Between November 16th and mid- December the Osprey made four voyages from Scrabster, near Dounreay to the port of Bremerhaven, carrying in total approximately 500kg of plutonium contained in 82 MOX fuel assemblies. BNFL plans to use the *Atlantic Osprey* for transporting plutonium MOX fuel between the UK and mainland Europe, in particular Germany, as well as shipments to and from the United States. It is also believed that it will be used to transport nuclear waste from Dounreay to Sellafield. *Source:* Greenpeace International, 2001

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13 Class I shipments to Germany with the SIFA system have been since October 1996 and six or more road/sea/road shipments have been undertaken since, and since the SIFA is not customed designed solely for MOX cargoes it was expected to be replaced with a MOX dedicated unit sometime around 2000 – see *The Transportation of MOX Fuel*, Christ R, 23rd Annual Symposium, Uranium Inst, 1998

14 *The Export of MOX Fuel to Switzerland – An Analysis of the Safety and Security Implications*, CORE, November 2002

15 IAEA INFCIRC/225/Rev 4

16 Up to now about 60 000 MOX fuel rods have been transported in the FS 65 and about 30 000 MOX fuel rods in the FS 65-1300 flask

17 Purcell P, *New Package for the Transport of Fresh MOX Fuel Assemblies in Europe*, Int. J. Radioact. Mat. Transp. 10(2), pp 85-90 (1999) - see also Purcell P, The Development of a Package for the Transport of New Mixed Oxide Fuel Assemblies within Europe, Int. J. Radioact. Mat. Transp. 9(2), pp 141-145 (1998)

18 BNFL Press release – CORE source.

19 During the period 1993-1999 Beznau-2 had alternating 11/18-month cycles and from 1999 Beznau-2 returned to 12-month cycles, with alternating very short fuel exchange (10 – 12 days) and longer (25 – 50 days) main service shutdowns. Beznau-2 will have a long shutdown in 2003, probably in the month June and / or July. 1997-2000 Beznau-1 had 11/18-month cycles, then returned to the 12-month cycles as described for Beznau-2. Beznau-1 will have a short service shutdown in 2003, probably also in June – source Leo Scherer, Greenpeace Switzerland, December 2002.

20 IAEA INFCIRC/225/Rev 4 gives the primary factor for determining the physical protection measures against unauthorized removal of nuclear material to be the nuclear material itself, categorized in accordance with the following table which gives a categorization of the different types of nuclear material and with the considerations given below:

Categorization of Nuclear Material

Material	Form	Category I	Category II	Category III[c]
1 Plutonium[a]	Unirradiated[b]	2 kg or more	Less than 2 kg but more than 500 g	500 g or less but more than 15 g
2 Uranium-235	Unirradiated[b] - uranium enriched to 20% ^{235}U or more - uranium enriched to 10% ^{235}U but less than 20% ^{235}U - uranium enriched above natural, but less than 10% ^{235}U	5 kg or more	Less than 5 kg but more than 1 kg 10 kg or more	1 kg or less but more than 15g Less than 10kg but more than 1 kg 10 kg or more
3 Uranium-233	Unirradiated[b]	2 kg or more	Less than 2 kg but more than 500 g	500 g or less but more than 15 g
4 Irradiated Fuel (The categorization of irradiated fuel in the table is based on international transport considerations. The State may assign a different category for domestic use, storage, and transport taking all relevant factors into account.)			Depleted or natural uranium, thorium or low-enriched fuel(less than 10% fissile content)d/e	

a All plutonium except that with isotopic concentration exceeding 80% in plutonium-238.

b Material not irradiated in a reactor or material irradiated in a reactor but with a radiation level equal to or less than 1 Gy/hr (100 rad/hr) at one meter unshielded.

c Quantities not falling in Category III and natural uranium, depleted uranium and thorium should be protected at least in accordance with prudent management practice.

d Although this level of protection is recommended, it would be open to States, upon evaluation of the specific circumstances, to assign a different category of physical protection.

e Other fuel which by virtue of its original fissile material content is classified as Category I or II before irradiation may be reduced one category level while the radiation level from the fuel exceeds 1 Gy/hr (100 rad/hr) at one meter unshielded.

21 IAEA INFCIRC/225/Rev 4 recommends a number of security measures, for example:

Security Guards: A 24-hour guarding service should be provided. Guards should be trained and adequately equipped for their function in accordance with national laws and regulations. When guards are not armed, compensating measures should be applied. The objective should be the arrival of adequately armed response forces in time to counter armed attacks and prevent the unauthorized removal of nuclear material.

Transfer of Responsibility: In contracts or agreements between shippers and receivers involving international transport of nuclear material, the point at which responsibility for physical protection is transferred from the shipper to the receiver

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should be clearly stated. During international transport of nuclear material the responsibility for physical protection measures should be the subject of agreement between the States concerned. The shipping State should consider, before allowing the international transport, if the States involved in the transport, including the transit States:

- are Parties to the *Convention on the Physical Protection of Nuclear Material* (INFCIRC/274 Rev.1); or
- have concluded with it a formal agreement which ensures that physical protection arrangements are implemented; or
- formally declare that their physical protection arrangements are implemented according to internationally accepted guidelines; or
- have issued licences which contain appropriate physical protection provisions for the transport of the nuclear material.

During international transport between two States sharing a common border, the State's responsibility for physical protection and the point at which physical protection responsibilities are transferred from one State to another should be the subject of an agreement between the States. However, with respect to the maintenance of communication regarding the continuing integrity of the shipment and with respect to the responsibility for carrying out physical protection measures and recovery actions in the event that a shipment becomes lost, the agreement between the States should provide that this responsibility will rest with the shipping State up to the border and will then be transferred to the receiving State.

When international shipments transit the territory of States other than the shipping State and the receiving State, the arrangements between the shipping and receiving States should identify the other States involved in such transit with a view to informing them and securing in advance their co-operation and assistance for adequate physical protection measures and for recovery actions on the territory of such States in case of loss of an international shipment thereon.

In the case of a Category I nuclear material international shipment transiting international waters or air space, the shipping and receiving States should establish specific measures to ensure the maintenance of communication regarding the continued integrity of the shipment and to ensure that responsibility for response planning and capabilities is defined and fulfilled. When the contract or agreement involving international transport provides for delivery to a destination in the receiving State in a vehicle of the shipping State, this contract or agreement should provide that information be supplied in time to enable the receiver to make adequate physical protection arrangements.

22 IAEA INFCIRC/225 states, for Category I materials, that the levels of physical protection for nuclear material during storage incidental to international nuclear transport include storage within a protected area to which access is restricted to persons whose trustworthiness has been determined, and which is under surveillance by guards who are in close communication with appropriate responses forces. Specific measures taken in this context should have as their object the detection and prevention of any assault, unauthorized access or unauthorized removal of material. The levels of physical protection for nuclear material during international transport include that transportation shall take place under constant surveillance by escorts and under conditions which assure close communication with appropriate response forces.

23 There is a plethora of regulations and statutes relating to the transportation of Category 1 materials in addition to the IAEA regulations (ST 1 & TS-R-1) for the safe transport of radioactive materials, including mode-specific regulations such as the *European Agreement for the International Carriage of Dangerous Goods by Road* (ADR - EC Directive 94/55/EC – *The Radioactive Material (Road Transport)(Great Britain) Regulations 1996*) and *The International Maritime Dangerous Goods* (IMDG) Code (INF-2 – *The Merchant Shipping (Dangerous Goods and Maritime Pollutant) Regulations 1997*). Referring to the IAEA 1996 Regulations approvals and compliance is required for Multilateral Shipment Approval (IAEA 820) and fissile packages (IAEA 566), special use vessels (IAEA 566), details of the proposed route, controls and shipment period (IAEA 822), flooding (IAEA 671), etc.. Special Provisions for vehicles carrying radioactive material are contained in Regulation 36 of the Radioactive Material (Road Transport)(Great Britain) Regulations 1996

24 Although the route to be taken to Beznau has not been published, nor is it likely to be made known in advance of the delivery, it is more than likely that it will proceed from a French Channel port and proceed to Switzerland via the French road network. If so, the road accident statistics are given in *Les transports de l'industrie du plutonium en france une activité à haut risque (The Transport Of The Industry Of The Plutonium In France - An Activity At High Risk)* Xavier COEYTAUX, Yacine B. FAID, Julie HAZEMANN, Yves MARIGNAC, Mycle SCHNEIDER, Sous la direction de : Yves MARIGNAC, 2003

25 The Atomic Energy Act 1959 SR 732.0, in particular Articles 8 & 39, and the Atomic Energy Ordinance 1984 SR732.11. Physical protection guidelines are set by the Convention on the Physical Protection of Nuclear Materials 1980 SR0.732.031 which is in accord with IAEA INFCIRC/225 with the Swiss guidelines in outlne form given in Physical Protection of Nuclear Facilities and Nuclear Material, Basic Guidelines, KE-R 01 August 2001.

26 The UK commitment to IAEA INFCIRC/225 is given in Note Verbale, dated 1 December 1997, communicating this to the Director General of the International Atomic Energy Agency (IAEA)

27 Letter, Sunil Parekh, APS to John Denham, Home Office Minister to Large & Associates, 10 May 2002

28 Letter, Mike Smith, Manager Nuclear Security, Department of Trade and Industry to Large & Associates, 28 February 2003 – see also the Office of Civil Nuclear Security 1st Annual Report, October to March 2002

29 E-mail Graham Holder, HSE to Large & Associates, 26 February 2003

30 Brown P, *The Threat that's Bigger than Ricin*, Guardian, 17 January

31 Large J H, *A Review of the Off-Site Emergency Plans under The Radiation (Emergency Preparedness & Public Information) Regulations, 2001* – see also *The Radiation (Emergency Preparedness & Public Information) Regulations, 2001*

32 Letters from HSK of 7 February and SFOE of 27 February in response to Large & Associates memo M3095-A12 of 30 January 2003.

33 When international shipments transit the territory of States other than the shipping State and the receiving State, the arrangements between the shipping and receiving States should identify the other States involved in such transit and secure in advance adequate physical protection measures and recovery actions on the territory of the transit States.

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34 Nuclear Terrorism: How real is the Threat, IAEA-CB-86-1 – see also, Large J H, Schneider M, *The implications of 11 September of the Nuclear Industry*, Oxford Research Group, Rhodes House, Oxford November 2002, Large J H, *The Aftermath of the US Attacks: The End of Probabilistic Risk Analysis, Rethinking Nuclear Energy and Democracy after 09/11*, PSR/IPPNW Switzerland, Basel April 2002

35 Luna R, *Comparison of Results from Two Spent Fuel Sabotage Source Term Experiments*, Int. J. Radioact. Mat. Transp. 11(1-2), pp 81-84 (2000)

36 Other applicable standards and codes include:-

- UN Committee of Experts on the Transport of Dangerous Goods "Recommendations on the Transport of Dangerous Goods - Model Regulations" (the "Orange Book")
- International Civil Aviation Organization (ICAO) - Technical Instructions for the Safe Transport of Dangerous Goods by Air
- International Maritime Organization (IMO) - International Maritime Dangerous Goods Code
- ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road
- ARID - European Agreement concerning the International Carriage of Dangerous Goods by Rail

37 Dyck H, Rawl R, et al *The Transportation of PuO, and MOX Fuel and Management of Irradiated MOX Fuel*, IAEA-SM-358/X, OECD Nuclear Energy Agency

38 IAEA 1996 Regulations, TS-R-1 – see also *Regulations for the Safe Transport of Radioactive Material, Safety Standards Series No. ST-l* Requirements, Edition, Vienna (1996)

39 IAEA-TECDOC-766, *Safe Handling, Transport and Storage of Plutonium*, October 1994

40 Small A1 and A2 quantities of radioactive material is allowed to release over a specified time period, although effectively the Type B(U) flask surety requirement is absolute.

41 The UK *Competent Authority* approval for flasks (the IAEA 1999 Regulations) provides opportunity for the Carrier to demonstrate the adequacy of the flask design by extrapolation from other designs, calculation or by reasoned argument (IAEA 701) and where testing is undertaken much of this is on part or scale models of the flask design.

42 The IAEA tests also include plate, torch and immersions tests – the IAEA recommendations were first set down in 1964 and seem to have been based on then prtactice by the United States and the UK who when then virtually the only carriers of irradiated fuel: The 9m or ~30mph drop test is little more than the average speed of the rail and road modes of carriage then adopted in the US and UK respectively, the punch test represents and upturned rail, and the thermal or fire test derives from a British Standard for money safes with 30 minutes at 800°C being about the time the that temperature inside a safe or strongbox would have reached the self-ignition temperature of paper money.

43 Lyman E, *Safety Aspects of Unirradiated MOX Fuel Transport, Comprehensive Assessment of MOX Use in Light Water Reactors*, IMA Project, Citizens' Nuclear Information Center, November 1997

44 The Atlantic Osprey was surveyed for the carriage of INF cargo with a full Certificate of Fitness being issued on 21 November 2002 – the certificate is not a publicly available document.

45 European Agreement Concerning the International Carriage of Dangerous Goods by Road and also the UK Radioactive Materials (Road Transport) Regulations

46 Large J H, *Import/Export of Irradiated Fuel and Radioactive Waste to and From the United Kingdom*, R1924-1, Greenpeace, 1994 – see also Harvey K, *Fires on Ships 1974-1984*, Trans IMarE, C, V98 c1/1, Sinclair C *Causes of Fires*, RINA/IMarE, Joint Symp 1972 and Tailor D H, *Problems of Fire Control on Board Ships*, Trans IMarE, C, V94, 1982 – the IMO statistics giving 23 and 20 hour durations for at sea and in berth fires respectively, include a standard deviation of 68 and 44 hours respectively.

47 Hutchinson B L, *Sub-Seabed Nuclear Waste Disposal Ship Conceptual Design and Accident Analysis*, Sandia SAND 87-7032 1987

48 The Summit (Derbyshire - UK) railway fire involving a petroleum tanker train and which burnt for 48 hours or more and at temperatures sufficient to vitrify the brick lining; the Channel Tunnel railway fire of temperature sufficient to cause explosions in the reinforced concrete liner, and the Mont Blanc road tunnel fire which raged for 24 hours or more – see also *Fires in Transport Tunnels: Report on Full-Scale Tests*, EUREKA-Project EU499:FIRETUN Studiengesellschaft Stahlanwendung elV. D-40213 Dusseldorf. 1995.

A summary of road tunnel fires is given by STUVAtec GmbHa follows:

						Consequences on		
Year	**Tunnel**	**Place**	**Vehicles at origin of fire**	**Probable cause**	**Duration**	**People**	**Vehicles**	**Tunnel**
1949	Holland L = 2.550 m	New York USA	1 lorry loaded with 11 t of carbon bisulfur	load falling of lorry	4 h	66 injured	10 lorries 13 cars	serious damage for 200 m
1968	Moorfleet L = 243 m	Hamburg Germany	1 lorry trailer (14 t of polyethene bags)	brakes jamming	1 h 30 min	none	1 trailer	serious damage for 34 m
1975	Guadarrama L = 3.330 m	Guadarrama Spain	1 lorry loaded with tanks of pine resin	unknown	2 h 45 min	none	1 lorry	serious damage for 210 m

1976	B6 L = 430 m	Paris France	1 lorry loaded with 16 t of polyester in bundles	unknown	1 h	12 slight injured (smoke inhalation)	1 lorry	damage for 150 m
1978	Velsen L = 770 m	Velsen Netherlands	2 lorries + 4 cars	front-back collision	1 h 20 min	5 dead 5 injured	2 lorries 4 cars	serious damage for 30 m
1979	Nihonzaka L = 2.045 m	Shizuoka Japan	4 lorries + 2 cars	front-back collision	4 days	7 dead 2 injured	127 lorries 46 cars	serious damage for 1.100 m
1980	Kajiwara L = 740 m	Japan	1 truck (4 t) with 3.600 l paint in 200 cans + 1 truck (10 t)	collision with side wall and overturning		1 dead	1 truck (4 t) 1 truck (10 t)	damage for 280 m
1982	Caldecott L = 1.028 m	Oakland USA	1 lorry + 1 coach + 1 car 33.000 l of petrol	front-back collision	2 h 40 min	7 dead 2 injured	3 lorries 1 coach 4 cars	serious damage for 580 m
1983	Fréjus L = 12.868 m	Modane France-Italy	1 lorry loaded with plastic materials	gear box breaking	1 h 50 min	none	1 lorry	serious damage for 200 m
1984	Felbertauern L = 5.130 m	Austria	1 bus	blocking brakes	1 h 30 min	none	1 bus	damage to ceiling and equipment for 100 m
1984	Gotthard L = 16.321 m	Goeschenen Switzerland	1 lorry loaded with rolls of plastic	fire in engine	24 min	none	1 lorry	serious damage for 30 m
1987	Gumefens L = 340 m	Bern Switzerland	1 lorry	mass collision on slippy road	2 h	2 dead	2 lorries 1 van	slight damage
1993	Serra Ripoli L = 442 m	Bologne Italy	1 car + 1 lorry loaded with rolls of paper	vehicle out of control and collision	2 h 30 min	4 dead some injured	4 lorries 11 cars	serious damage to lining
1994	Gotthard L = 16.321 m	Goeschenen Switzerland	1 lorry + trailer loaded with bikes wrapped in carton and plastic	friction between wheels and loading bridge	2 h	none	1 lorry + trailer	serious damage to ceiling, pavement and equipment for 50 m, tunnel closed for 2,5 days
1995	Pfänder L = 6.719 m	Austria	1 lorry + 1 van + 1 car	collision	1 h	3 dead (by crash)	1 lorry 1 van 1 car	serious damage to ceiling and equipment, tunnel closed for 2,5 days
1996	Isola delle Femmine L = 150 m	Italy (Sicilia)	1 tanker with liquid gas + 1 little bus	wet road collision of a bus with a tanker (stopped because of a previous collision), explosion	unknown	5 dead (by fire) 20 injured	1 tanker 1 bus 18 cars	damages to the tunnel lining and lighting equipment
1999	Mont Blanc France L = 11.600 m	France-Italy	1 lorry loaded with 20 tons of margarine and flour	fire in engine	>50 h	42 dead 27 injured	34 vehicles	serious damage to about 100 m of ceiling
1999	Tauern L = 6.400 m	Austria	1 lorry loaded with paint	front-back collision	17 h	12 dead more than 50 injured	16 lorries 24 cars	serious damage, tunnel closed for about 3 months

49 Ammerman D, *Crush Loadings to Radioactive Material Transport Packages During Ship Collisions*, Int. J. Radioact. Mat. Transp. 9(2), pp 147-156 (1998) – in this analysis a seagoing RAM ship is involved in a collision accident being struck by another commercial vessel with sufficient tonnage and velocity - the RAM package is impacted by the penetrating bow of the striking ship. The impact on the RAM package by the bow is found to be less damaging to the package than the IAEA 9 m drop test. This is because the velocity is always lower and the bow always less rigid than the essentially unyielding target required for the drop test. The other mechanism for gross damage to the package is crush loading with the bow of the impacting ship is assumed to be able to impart an infinite force to one side of the package and with the opposing force being the hull of the struck ship on the side away from the collision. Resistance of this hull to penetration by the package determines the maximum magnitude of the crush force. The analysis does not consider a situation where the ramming occurs when the RAM ship is berthed against a robust dock or quayside wall.

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50 Locke J, *Marine Casualty Statistics*, US Coastguard, Washington 1979 – see also, Van de Tak *Model for Calculating a Martime Risk Criterion Number*, J Nav V30, N^o 2 1977, Fujji T *The Analysis of Traffic Accidents*, J Nav V24, N^o 4 1971

51 Over a ten year period, excluding tankers, the risk of fire has been reckoned to be 0.00029 per year – see Kay D, *Frequency of Fire on a Vessel Carrying Nuclear Fuel*, Int. J. Radioact. Mat. Transp. 9(2), 1998

52 Of course these collisions and fire rates, crudely extrapolated here to the *Atlantic Osprey* are not limited to severely damaging events at sea but include minor incidents (bumps and scrapes) that would not necessarily imperil ship or cargo. Equally, no account is taken of the routing of the *Atlantic Osprey* , particularly in that it will be operating in the extremely busy shipping lanes of the Irish Sea, the Channel and North Seas, which could significantly increase the risk – a fuller treatment of the risks at sea is given in Ref 46.

53 It might be that two SIFA units will be involved, one carrying the MOX cargo and a second unit in reserve and also acting as a decoy.

54 HM Department of Transport Annual Statistics – *Road Accidents*, published annually

55 Hunting, *The Probability of Traffic Accidents Associated with the Transport of Radioactive Wastes*, TP 27930, HM department of Environment, 1986

56 Allsop R, *A Methodology for Assessing Social Considerations in Transport of Low and Intermediate Level Radioactive Wastes*, Transport Studies Group, UCL 1987

57 For a fuller analysis of the road accident risks see Large J H, *Transportation of Nuclear Weapons through Urban Areas in the United Kingdom*, R1784, Ch 4, 1980

58 *The Radiation (Emergency Preparedness and Public Information) Regulations* (REPPIR) are intended to implement articles 48 to 52 on intervention in cases of radiation emergency in an European Council Directive on the basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation (Euratom BSS96 Directive).

59 *The Radioactive Material (Road Transport)(Great Britain) Regulations 1996*

60 The NII confirmed such by e-mail of 5 February 2003:

“. . .

Your message of 27/01/03 to my colleague Graham Holder refers.

The Health and Safety Executive has not been involved in testing an accident or incident representative of the proposed shipment of MOX fuel to Beznau, neither have HSE and OCNS discussed the shipment.

I am unaware of any need the OCNS would have to discuss matters of health and safety with the Radioactive Materials Transport Division (RMTD), of the Department for Transport. However, I have no doubt that RMTD as the Competent Authority in relation to the safety in transit of the fuel, would contact HSE, if any general concern relating to radiation safety were to arise.

Michael Redhead,
Health and Safety Executive,
Safety Policy Directorate,
Nuclear and Hazardous Installations Policy Division

61 *Transport of MOX Fuel from Europe to Japan,* Information File, BNFL, June 1999

62 GP International anecdotal evidence of Submarine sighting

63 *Transport of MOX Fuel from Europe to Japan*, Information File, BNFL, COGEMA, ORC, June 1999

64 Ref 14 states for the Japanese delivery *“At that time, prior to the shipment to Japan, the Pacific Pintail and Pacific Teal were layed-up in dock in Barrow whilst extensive alterations and additions were made. This included the construction of extra accommodation for a thirteen strong-security crew. The fitting of three 30mm naval canon to each ship plus fire control accommodation and radar systems. A fast RIB craft with launching derrick was fitted to each ship.”* And for the proposed Beznau delivery *“The Atlantic Osprey has also undergone some modifications in various docks around the UK (principally Manchester and Birkenhead) over the last year, but has emerged only with extra accommodation – probably for use by a security crew of similar size to that provided for Japan. From CORE’s own observations during the year, there is no sign of any naval armament having been fitted nor the addition of an RIB for added protection”.*

65 Letter dated 27 January 2003 from Brian Wilson, Minister of State for Energy and Construction, Department of Trade and Industry to Chris Davies MEP in response to his letter of 4 November 2003.

66 *Appraisal for the United Kingdom of Safety of the Transport of Radioactive Material*, IAEA Safety Standards Applications, IAEA TranSAS-3, 2002 – see also IAEA *Guidelines for Developing Shipboard Emergency Plans for Ships Carrying Materials Subject to INF Code* .

67 The DTi claim that the US-Japanese arrangements have to comply with the terms of the 1988 bilateral agreement on nuclear co-operation between the US and Japan, noting that this agreement includes the requirement for vessels undertaking movements by sea of US obligated plutonium to be accompanied by an armed escort vessel. The provisions of the US-Japan agreement apply only in respect of transports of US obligated plutonium.

68 Responses to the memorandum of 31 January 2003 from Large & Associates to i) DfT Division of Radioactive Materials Transport and iii) the Office of Civil Nuclear Security – a similar approach to the Swiss regulator Hauptabteilung für die Sicherheit de Kernanlagen (HSK) attracted much the same unhelpful response, although a later letter of 7 March from HSK was more forthcoming in detail – see Appendix IV for the full correspondence.

69 The reactor in-core thermal and mechanical performances are similar to UO_2 fuel, although there is a reduced drop of reactivity with burn-up, leading to increasing fission gas release and higher rod inner pressure at the end of life of MOX fuel; also the nuclear self

shielding is more pronounced and, hence greater heat is generated at the periphery of MOX fuel and this mitigates the generally poorer thermal properties of MOX fuel – *In-Pile Performance of Mixed Oxide Fuel with Particular Emphasis of MIMAS Fuel*, Deramaix P and Haas D, Nuclear Technology 102, April 1993

70 For reactor grade reprocessed plutonium, at about 65% Pu-239 with Pu-238, 240, 242 isotopes forming the remainder, 7% Pu-239 content MOX is equivalent to 4.5% U-235 enrichment. In addition up to 3-4% Americium-241 will be bound into the plutonium. The Pu-239 content of the Beznau is Pu-239/Pu all = 71.3% - see Safety Report Kenndaten Des Referenzkerns von 1991.

71 The oxides best suited for subsequent pressing and sintering into pellets are made from uranium/plutonium compounds precipitated from uranyl salt and plutonium nitrate (by oxalate precipitation) solutions that are subsequently reduced to the respective oxides (UO_2 and PuO_2) by firing. The oxide products have a large surface to volume ratio, low bulk and packing density, and a moderate to high oxygen to uranium/plutonium ratio. The two oxides are thoroughly mixed with additives to produce a homogenised powder, thereafter these are blended and milled and then tumbled in a spheroidiser to produce granulated powder. During these processes a dry lubricant/conditioner (a zinc based stearate and a porosity control agent) is added. The granulated powder is milled, pressed and sintered under a reducing argon-hydrogen atmosphere to produce a sintered, fused matrix of (crystalline) ceramic dioxide in the form of individual, cylindrical pellets of approximately 20 to 25mm length and 10 to 12 mm diameter, depending on the host reactor requirements.[71, 71] When sintering UO_2-PuO_2 green pellets, the uranium plutonium and oxygen atoms interdiffuse to form a solid solution of $UPuO_2$. However, because the rate of diffusion of the metal atom is very slow (10^{-12} cm^2/s) it is likely that pure PuO_2 particles of about 30 micron diameter will not completely convert into MOX particles because of the slow rate of U-Pu diffusion. Plutonium homogeneity throughout the pellet aims to reduce plutonium agglomeration to 400 microns or less, although the UK MOX producer, BNFL, claims that in practice its product contains few agglomerates or 'clumps' as large as 20 to 30 microns.[71] The final stage of pellet manufacture is to grind the end and radial surfaces to within a final dimensional tolerance.

72 There are four plants worldwide currently producing commercial quantities of MOX fuel. Two are in France, one in Belgium, and a fourth at Sellafield in the United Kingdom is presently running through the final stages of its commissioning. In 2000, about 190 tonnes of MOX was produced, incorporating 10-12 tonnes of plutonium and the present capacity, including the Sellafield plant, is around 300t/yr. MOX has been and continues to be promoted as a means by which the plutonium of the World's nuclear weapons arsenals might be dissipated in peaceful use.

73 The Swiss electricity utilities signed reprocessing contracts with COGEMA and BNFL for a total amount of fuel to be reprocessed of between 1,000 and 1,100 tonnes which corresponds to about one third of the total quantity of fuel produced during forty years of operation of the five Swiss power plants. With this reprocessing contract, Switzerland is entitled to a considerable amount of separated plutonium.. It is highly probable that the total plutonium produced through the reprocessing of Swiss spent fuel will not all be used as MOX fuel and Switzerland, as other States, is likely to be confronted with a significant plutonium stockpile which will require long term safe and secure storage.

74 There is some ambiguity on whether the nuclear industry defines MOX as LDM, although BNFL certainly implied that MOX is LDM with its press release *Air Transport of Mixed Oxide (MOX) Fuel: The Facts*, 12 June 1997 which stated *"Even in a hypothetical scenario where the container was damaged to such an extent that it was split open, the MOX fuel inside would not disperse in air – it is hard, stone-like and cannot be disintegrated to a powder"* although it subsequently retracted this or a similar claim in a letter to G L Cox of 13 October 1997, noting that *"With regard to MOX and LDM., I apologise for implying that MOX fuel has in any way been officially classified as Low Dispersible Material. This was not a deliberate attempt to mislead you. BNFL, in collaboration with other European transport organisations and MOX fuel fabricators, is currently developing a reproducible and robust test regime to demonstrate LDM under funding from the EU."*

75 As yet MOX has not been officially accepted as LDM.

76 *Requirements for Very Low Dispersible Material (VLDM)*, TC-946, F Lange, F Nitsche, F-W Collin and M Cosack, Working Paper No 11, IAEA Technical Committee Meeting, Vienna, 15-19 May 1995

77 *Contribution to Technical Committee Meeting, Working Paper 8*, F Lange and F Nitsche, IAEA Vienna, 29 August - 2 September 1994

78 Refs 76 and 77 do not actually specify that any of the presently manufactured MOX fuels qualify as LDM but rather set a qualification test for any radioactive substance that is to qualify for air transportation materials which must be LDM – *see IAEA Safety Series 6, Regulations for the Safe Transportation of Radioactive Materials* – which introduces the so-called *Type C* qualification test that applies an impact velocity of 90m/s and a 1 hour fire at 800°C. The substance qualifies as LDM if, during and following the tests, does not release an amount of activity greater than 100 times the A2 index in gaseous and particulate forms of up to 100 microns in diameter.

79 The IAEA SS6 Regulations apply as Type C qualification but the matter of LDM remains under investigation by the parties with the IAEA Transport Safety Standards Advisory Committee (TRANSACC) which recommended at its March 1997 meeting that *"the new Coordinated Research Programme (CRP) on 'Accident Severity during air transport of radioactive material' be advances as planned, particularly including for the participation of the International Civil Aviation Organisation"*

80 There is some ambiguity on whether the nuclear industry defines MOX as LDM, although BNFL certainly implied that MOX is LDM with its press release Air Transport of Mixed Oxide (MOX) Fuel: The Facts, 12 June 1997 which stated "Even in a hypothetical scenario where the container was damaged to such an extent that it was split open, the MOX fuel inside would not disperse in air – it is hard, stone-like and cannot be disintegrated to a powder" although it subsequently retracted this or a similar claim in a letter to G L Cox of 13 October 1997, noting that *"With regard to MOX and LDM., I apologise for implying that MOX fuel has in any way been officially classified as Low Dispersible Material. This was not a deliberate attempt to mislead you. BNFL, in collaboration with other European transport organisations and MOX fuel fabricators, is currently developing a reproducible and robust test regime to demonstrate LDM under funding from the EU."*

81 Am241 is an important contributor to radiation and neutron emissions from the MOX fuel in transit with the Tl^{208} decay daughter of Pu^{236} being a 2.6-MeV gamma ray source – see also S. B. Ludwig, et al, *Revised Conceptual Designs For The FMDP Fresh Mox Fuel Transport Package,* Oak Ridge National Laboratory, Chemical Technology Division, ORNL/TM-13574, 1998

82 The US Department of Energy has given precise statistics about the MOX fuel sent from Sellafield (produced in the MOX Demonstration Facility) and to be returned to Sellafield because quality control data were falsified. The The total amount of plutonium in the MOX fuel is 255.086 kilograms and the amount of uranium is 3,439.377 kilograms. The percentage of plutonium (including non-fissile) in the MOX fuel is, therefore, 6.9 percent.

83 The Fuel Assembly comprises – source *Safety Report* Kenndaten Des Referenzkerns von 1991:

CORE GRADE	PU FISSION	PU TOTAL	PINS PER ASSEMBLY	PU FISS/TOTAL %
LOW	2.300 %	3.228 %	12	71.3
MIDDLE	2.940 %	4.123 %	52	71.3
HIGH	4.160 %	5.835 %	115	71.3
AVERAGE	**3.680%**	**5.160 %**	**179**	**71.3**

84 The approximate isotopic composition of various grades of plutonium are given in *Plutonium Fuel: An Assessment, Paris:OECD/NEA,* 1989 and Micholas N, Coop K, Estep R, *Capability and Limitation Study of DDT Passive-Active Neutron Waste Assay Instrument* Los Alamos National Laboratory, LA-12237-MS, 1992:

Grade	**Isotope**				
	Pu-238	**Pu-239**	**Pu-240**	**Pu-241**[a]	**Pu-242**
Super-grade	-	.98	.02	-	-
Weapons-grade	.00012	.938	.058	.0035	.00022
Reactor-grade[b]	.013	.603	.243	.091	.050
MOX-grade[c]	.019	.404	.321	.178	.078
FBR blanket[d]	-	.96	.04	-	-

a. Pu-241 plus Am-241.

b. Plutonium recovered from low-enriched uranium pressurized-water reactor fuel that has released 33 megawatt-days/kg fission energy and has been stored for ten years prior to reprocessing

c. Plutonium recovered from 3.64% fissile plutonium MOX fuel produced from reactor-grade plutonium and which has released 33 MWd/kg fission energy and has been stored for ten years prior to reprocessing

d. FBR=Fast-neutron plutonium Breeder Reactor

85 The equilibrium temperature is about 50°C for 4.5 kg of plutonium metal suspended in moderately static air.

86 There is also the decay of Pu^{236} into Bi^{212} and Tl^{208} yielding gamma, all at about one-fifth the rate of the Am^{241} accumulation – the rate of gamma activity increase depends on the 'quality' of the plutonium used and, of course, the decay series cited commence at and are dated from the in-core life of the original fuel source of the plutonium.

87 The helium production rate is approximately 0.3 micromole/day per kg of Pu. The Americium rate increases by approximately 0.5% pr year. Over longer storage periods the generation of helium bubbles in the fuel matrix could have a significant impact on the fissioning processes of the in reactor core fuel, although several if not many years of storage would be required for this.

88 Barnaby, F, *The New Terrorism – A 21st Century Biological, Chemical and Nuclear Threat,* Oxford Research Group, 2001

89 About 35kg of plutonium in the PuO_2 oxide form is required to make a nuclear-fission weapon. This amount of plutonium is contained within 700 Kg of MOX fuel pellets, so three typical fuel assemblies are required from which the PuO_2 has to be extracted. If in metal form, the fissile mass of plutonium-239 required as about 12 to 13kg but for this the PuO_2 has to be reduced to its base elemental metal form.

90 A lower melt temperature of ~1,800°C might more realistically apply since the melting point of stoichiometric MOX (at 5% plutonium) is about 20°C below that for UO_2.

91 Seehars H, *Durchfuhrung Experimenten zur Unterstutzung de Annahmen zur Freisetzung von Plutonium bei einem Flugzeugabsturz,* - Franhofer-Institute, SR 0205A, March 1982

92 Here it is assumed that the thermo-mechanical forces occurring during the incident are sufficient to fail the fuel transport or storage package and break through the zirconium alloy cladding.

93 Less than 10 μm in equivalent aerodynamic diameter.

94 *Inadequacy of the IAEA's Air Transport Regulations: The Case of MOX Fuel,* E Lyman, Nuclear Control Institute, Washington, October 1997

95 *Import/Export of Irradiated Fuel and Radioactive Waste to and from the United Kingdom*, Large & Associates, Greenpeace UK R1924-1, 1995

96 Macdonald, *Fuel Incident,* letter of 7 November 1983 Relating to the Haddom Neck PWR fuel oxidation Incident of 1983 at the Battelle Columbia Laboratory

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97 Lamb M, *Radiological Consequences of Severe Rail Accidents Involving Spent Nuclear Fuel Shipments to Yucca Mountain: Hypothetical Baltimore Rail Tunnel Fire Involving SNF*, , Radioactive Waste Management Associates September 2001

98 For example of a severe road tunnel fire see Mont Blanc road tunnel fire of March 1999 which burnt for 3 days and resulted in 39 fatalities.

99 *Import/Export of Irradiated Fuel and Radioactive Waste to and from the United Kingdom*, Large & Associates, R1924, August 1995

100 The reaction strips oxygen and liberates hydrogen thus $Zr + 2H_2O > ZrO_2 + 2H_2$ which liberates –9,878kJ/kg of energy (heat) – the reaction is slow at 870^{o}C but thereafter rapidly increases following a phase change of the unoxidised zirconium above 997^{o}C.

101 *Fuel Accident*, Letter of 7 November 1983 relating to *PWR Fuel Oxidation Incident of 1983 at the Battelle Columbia* Laboratory, MacDonald – see also *Uranium Properties and Nuclear Applications*, Bell J, AE (USA), 1961 and *The Release of Fission Products from Zircalloy Clad UO_2 Fuel at around 1000^{o}C*, Hillary J et al, UKAEA, TRG 2433(W), 1973

102 Hence smaller particulate size, greater respiratory uptake and the potential for reconcentration of plutonium in the organs.

103 Under these conditions plutonium differs inasmuch that the volatility of decay product americium-241 may be enhanced in reducing conditions.

104 'Dispersible-sized' particles are usually taken as being less than 100 microns – strictly these results apply to uranium dioxide pellets, although the plutonium oxide component should particularise similarly.

105 Walton A, *The Assessment of Risks Associated with the Carriage by Air of Radioactive Material*, Cranfield Impact Centre August 1997

106 *Behavior of Transport Casks Under Explosive Loading* Didier Brochard, Bruno Autrusson, Franck Delmaire-Sizes, Alain Nicaud, Institut de Protection et de Sûreté Nucléaire; F. Gil, CS Communications et Systems Group; J.M. Guerin, P.Y. Chaffard, F. Chaigneau, CEA/DAM Ile de France

107 Yoshimura M, Luna R, *Spent Fuel Cask Sabotage Investigations*, Richard Yoshimura, Manuel Vigil, Robert Luna, SNL – see also *International Initiatives in Transportation SabotageInvestigations* Richard, SNL; Bruno Autrusson, Didier Brochard, IPSN/DSMR/SATE; Gunter Pretzsch, GRS; Frances Young, J.R. Davis, US NRC; Ashok Kapoor, US DOE, F. Lange, Gesellschaft für Anlagen-und Reaktorsicherheit - Dietrich, A.M., and W.P. Walters, *Review of High Explosive Device Testing Against Spent Fuel Shipping Casks*, Prepared by U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Prepared for U.S. Nuclear Regulatory Commission, 1983.

108 Halstead R, *Nuclear Waste Transportation Terrorism and Sabotage: Critical Issues*, State of Nevada, Agency for Nuclear Projects; James David Ballard, Grand Valley State University, School of Criminal Justice; Fred Dilger, Nuclear Waste Division, Clark County, Nevada - Audin, L., *Analyses of Cask Sabotage Involving Portable Explosives: A Critique*, Draft Report, Prepared for Nevada Agency for Nuclear Projects/Nuclear Waste Project Office, 1989

109 Schmidt, E.W., Walters, M.A. and Trott, B, *Shipping Cask Sabotage Source Term Investigation*, Batelle Columbus Lab., Columbus, NUREG/CR-2472, BMI-2095 (Oct. 1982)

110 *Experiments to Quantify Potential Releases and Consequences from Sabotage Attack on Spent Fuel Casks* Florentin Lange, Gunter Pretzsch, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH; Eugen Hoermann, Dornier GmbH; Wolfgang Koch, Fraunhofer Institute for Toxicology and Aerosol Research

111 Current portable anti-tank weapons are:

WEAPON	COUNTRY	WEIGHT	RANGE	WARHEAD Ø/KG	ARMOUR PENETRATION
Milan Anti-Tank Missile	France	32 kg	2000 m	133 mm/3.12 kg	>1000 mm
Eryx Anti-Tank Missile	France	21 kg	600 m	160 mm/ 3.8 kg	900 mm
Panzerfaust 3 Anti-Tank Launcher	Germany	13 kg	300 m	110 mm/NA	>700 mm
Folgore Anti-Tank System	Italy	21 kg	4500 m	80 mm/3 kg	>450 mm
Apilas	South Africa	9 kg	330 m	112 mm/NA	>720 mm
RPG-7 Anti-Tank Launcher	Soviet Union	11 kg	300 m	85 mm/NA	330 mm
C-90-C Weapon System	Spain	5 kg	200 m	90 mm/NA	500 mm
AT-4 Anti-Tank Launcher	Sweden	7 kg	300 m	84 mm/NA	>400 mm
Carl Gustav M2 Recoilless Gun	Sweden	15 kg	700 m	84 mm/NA	>400 mm
LAW 80 Anti-tank Launcher	U.K.	9 kg	500 m	94 mm/NA	700 mm

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M72 66mm Anti-tank Launcher	USA	4 kg	220 m	66 mm/NA	350 mm
SMAW	USA	14 kg	500 m	83 mm/NA	>600 mm
AT-8 Bunker Buster	USA	8 kg	250 m	84 mm/NA	NA
Superdragon Anti-tank Missile	USA	17 kg	1500 m	140 mm/10.07 kg	>500 mm
TOW 2 Anti-tank Missile	USA	116 kg	3750 m	127 mm/28 kg	>700 mm
Javelin AAWS/M	USA	16 kg	2000 m	127 mm/NA	>400 mm

112 The MI6 intelligence agency building attack in London on 21 September 2000 used a Russian-built RPG Mk 22 anti-tank weapon which has a range of 250m for a 72.5mm diameter self-propelled round – this weapon takes about 10 second to prepare, aim and discharge – the round has a two stage charge, first armour piercing penetration than a pop-off explosive grenade.

113 The Federal Ministry of Environment, Nature Protection and Reactor Safety (BMU) instructed Dornier, Friedrichshafen to organize the trials and supervise the whole project. The Fraunhofer Institute for Toxicology and Aerosol Research (FhG-ITA), Hanover, designed and carried out the aerosol measurements. The trials were carried out in the Centre d'Étude de Gramat (CEG) in France in 1992 which is a research facility where missiles which include depleted uranium are tested for military purposes.

114 *Physical Protection of Shipments of Irradiated Reactor* Fuel, NUREG-0561, Rev. 1, 1980

115 Shaw K, *The Radiological Impact of Postulated Accidental Releases during the Transportation of Irradiated PWR Fuel through Greater London*, NRPB-R147, 1983

116 *Comparison of Results from Two Spent Fuel Sabotage Source Term Experiments* Luna, R.E. Int. J. Radioact. Mat. Transp. 11(1-2), pp 81-84 (2000)

117 Elder H, An Analysis of the Risk of Transporting Spent Nuclear Fuel by Train, Battelle, PNL-2682, 1981

118 Only particles with aerodynamic equivalent diameters AED < 10 mm are considered to be respirable and to contribute to radiation exposure via inhalation. For other exposure pathways such as groundshine the deposition velocity which depends on the aerodynamic diameter influences the level of ground contamination from dry or wet deposition.

119 Eastmen R J, Tod S, *The Microstructure of Unirradiated SBR Mox Fue,* IAEA-SM-358/9 British Nuclear Fuels plc

120 Greenpeace UK activists entered the inner security compounds recently on two occasions – first in December 2002 when 150 individuals broke through the security fence and occupied the roof of the main control building and in January 2003 when a smaller group of 19 individuals broke in and occupied parts of the reactor control building and it roof, climbing onto the dome of the reactor secondary containment.

121 Arnold L, *A Very Special Relationship*, HMSO – see also Ref 57

122 The Royal Commission into British Nuclear Tests in Australia, 1985 - Australia Nation Archives

123 The first benchmark condition is where the both of the FS 69 flasks leak an aerosol of the fuel at the maximum A2 limit as prescribed by the IAEA specification.[38] The A2 amounts are prescribed to provide some flexibility on the performance of the flask from flask body distortion and, particularly, failure of the elastomeric sealing materials used at the flask lid/body interface. The A2 quantity is defined as the amount of a particular radionuclide that is permitted to leak over a period of one week, although here it is assumed that the leakage and release occurs within 2 hours and that no countermeasures is the public domain are implemented for 24 hours following the release.

124 In the UK a system of Emergency Reference Levels (ERLs) are deployed. For sheltering these are arranged in Lower (3mSv) and Upper (30mSv) levels and for evacuation 30mSv Lower and 300mSv upper – the countermeasure should not be undertaken before the Lower exposure level but should be implemented to prevent the individual reaching or exceeding the Upper level.

125 The Expectation value of a probability distribution is the arithmetic mean or the average value of the distribution – it would represent the average number of consequences (outcomes) were the same accident to occur a large number of times. In general, the Expectation value will differ from the Median value of the distribution where the Median value of a distribution is the value that would be exceeded with a probability of 0.5.