Large and ASSOCIATES
Consulting Engineers

The Gatehouse 1-2 Repository Road Ha Ha Rd London UK SE18 4BQ1 ☎ 44[0]20 8317 2860 *fax* 8317 2859 *mobile* 07971 088 086 mailto:largeassociates@msn.com

POTENTIAL RADIOLOGICAL IMPACT ARISING FROM A SEVERE FIRE ON BOARD MV FRET MOSELLE CARRYING A CONSIGNMENT OF IRRADIATED REACTOR FUEL FROM AUSTRALIA TO FRANCE

APPROACHES TO CAPE HORN

CLIENT: GREENPEACE INTERNATIONAL

REPORT REF: R3111-A1.Doc

1ST ISSUE	REVISION No	APPROVED	PRESENT ISSUE
5 November 2003	R2		28 July 2013

Large and ASSOCIATES
Consulting Engineers

POTENTIAL RADIOLOGICAL IMPACT – APPROACHES TO CAPE HORN

RADIOACTIVE CARGO

At this time, a cargo of irradiated fuel is on the high seas on route from Australia to France.

The cargo comprises 344 nuclear reactor fuel rods that have been irradiated in the core of the radio-isotopic production reactor HIFAR[4] (High Flux Australian Reactor) located at Lucas Heights near Sydney. This consignment of spent fuel has accumulated during the equivalent of 10 years of reactor operation.

Each fuel element comprises four cylindrical rings or tubes clustered concentrically together. Each tube carries an enriched uranium wafer of uranium/aluminium ceramic-like fuel alloy sheathed in a thin aluminium cladding. The original (unirradiated) enrichment level was approximately 60%, giving 170 gram highly enriched uranium (HEU) of the 280g total uranium content of each complete fuel assembly.

A scale representation of the HIFAR reactor core, showing the cylindrical fuel elements each of about 1m length

Assuming an average of 10-year post (reactor) core radioactive decay, the fission product (radio)activity of each fuel element would be approximately 33,300GBq with about 400GBq of actinides. The total activity of the transport consignment will be approximately 11,455TBq fission products and 137.6TBq actinides (310.10^3 Curies and 4.10^3 Ci respectively).

CONSIGNMENT SAFETY AND SECURITY REQUIREMENTS

Irradiated fuel is defined by the International Atomic Energy Agency (IAEA) to be *Category II*[5] material and is thus required to satisfy specific requirements and safeguards relating to safety and security. The physical design and performance of flasks carrying Category II radioactive materials are required to satisfy domestic (state) legislation mostly derived from the IAEA *'Regulations for the Safe Transport of Radioactive Material'*,[6] and other regulations, etc., relating specifically to irradiated fuel and fissile materials (enriched uranium).[7] 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

---

4 HIFAR - High Flux Australian Reactor – is a 5MW thermal power reactor with a heavy water moderator. The reactor was installed and commissioned by the UK 1958, apparently in support of the UK's nuclear weapons test programme then underway in Australia and the Pacific.

5 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 – in fact, the highly enriched uranium content is downgraded from its normal Category I status because the fuel has been irradiated which, in itself, is considered to provide an additional security barrier.

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

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

Large and ASSOCIATES Consulting Engineers

when subject to both normal and accidental conditions of transport.

Details of the packaging of the fuel consignment are not known, although the consignment is likely to be carried in five Type B(U)/F fuel flasks (most likely, dry fill Transnuclier TN72 flasks located in the single cargo hold of the carrying vessel (*MV Fret Moselle*).

In terms of security, unlike low enrichment uranium oxide nuclear fuel, there is an additional degree of physical protection required for highly enriched fuels in transit because it contains highly enriched uranium – it is estimated that the irradiation or burn-up of the consignment fuel contains in total a residue about 40kg of HEU which, once extracted and refined, could be used in a nuclear weapons programme.[8]

The IAEA recommendations[9] on security, physical protection systems and sabotage prevention are specified in general terms, the salient features of which are as follows:

- 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.
- 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
- 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.

8 Obviously, extraction and refining of the enriched uranium would required a relatively sophisticated plant and such is believed to be beyond terrorist groups such as Al-Qaeda, although developing states, such as North Korea, clearly have the capacity to carry out the necessary processes.

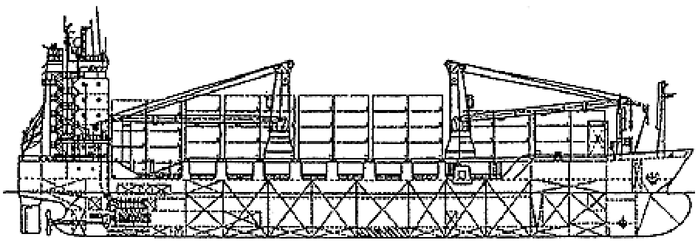
9 IAEA 1996 Regulations, TS-R-1 – see also *Regulations for the Safe Transport of Radioactive Material, Safety Standards Series No. ST-1* Requirements, Edition, Vienna (1996) and *The Physical Protection of Nuclear Material* (INFCIRC/274 Rev.1)

- o 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 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.

TRANSPORT VESSEL

The fuel consignment is being hauled by the *MV Fret Moselle* which is a general cargo vessel operated by Louis Dreyfus Group, a French group of companies, managed by Harren & Partner, registered under a flag of convenience in Antigua and Barbuda, and believed to be manned by a Russia/German/Ukrainian crew.

At a gross tonnage of 6,275 tonnes, the *Fret Moselle* is a single cargo hold freighter of 118m length and 20m beam, classified as INF Class II.[10] Fuel oil capacities are 650m3 heavy fuel oil and 110m3 medium diesel – running from Portland, Australia at the approach to Cape Horn fuel remaining would total about 530m^3.



There is no record of the *Fret Moselle* being used for nuclear transports in the past, nor is there any information on the training and experience of the crew in handling nuclear transports, including in the event of accident.

TRANSIT ROUTE

Three sea routes from Potland to Cherbourg, France, are viable:

- via Cape Horn – this would take the Moselle between 34 and 51 days
- via Panama Canal – this would take the Moselle between 34 and 47 days
- via South Africa – this would take between 35 and 48 days.

Fret Moselle is the route option adopted and the vessel is now approaching Cape Horn from the West.

10 INF – Irradiated Nuclear Fuel carrier as defined by the International Maritime Organisation (IMO).

HAZARDS AND RISKS

All nuclear transports carry risks, all are subject to hazards, and the cargo, in itself, is hazardous. An incident at sea might lead to and result in a release of radioactive material to either or both marine and atmospheric environments.

Groups of individuals at risk of exposure include:

- the crew of the *Fret Moselle*
- other seafarers in the vicinity of the *Fret Moselle* or those who provide assistance
- individuals and communities on land contaminated by fall-out from the atmospheric release plume
- fisherman and seafood consumers of fish and other marine life taken from contaminated waters

Aspects of the natural environment at risk of contamination include:

- the marine environment, particularly shallow coastal shelves
- the terrestrial environment by deposition or fall-out from the release plume
- the inter-tidal environment

RADIOACTIVE RELEASE SCENARIOS FOR THE APPROACH TO CAPE HORN

The following analysis considers an incident whereby a fraction of the (radio)activity of the *Fret Moselle*'s fuel consignment is released to atmosphere.

The incident scenario is based on a severe fire involving the fuel oils carried on board. The fuel and fire is assumed to spread to the single cargo hold, wherein 30% of the fuel remaining at Cape Horn burns. The fire is assumed to burn over an equivalent free surface of 4m radius at a replenishing pool depth of 10mm, with fuel consumption at between 1 to 5mm depth per minute, which provides a fire duration of 11 to 12 hours.

Temperatures and, particularly, fire duration within the single cargo hold are considered sufficient to rupture the fuel transits flasks[11] and further oxidise the fuel within, resulting in a 20% release fraction of the entire inventory of the fuel consignment, commencing 3 hours from the onset of the fire, continuing uniformly for 9 hours thereafter.

---

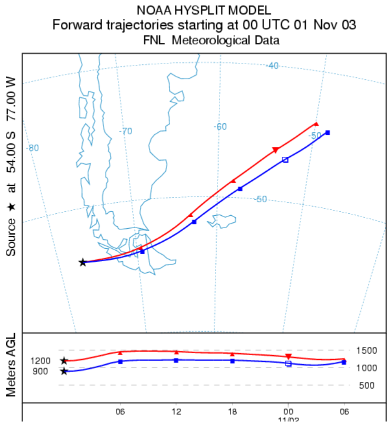
11 The IAEA regulations require the flask to maintain surety during and following fire engulfment at 800^{o}C for 30 minutes.

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 practice 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^{o}C being about the time the that temperature inside a safe or strongbox would have reached the self-ignition temperature of paper money.

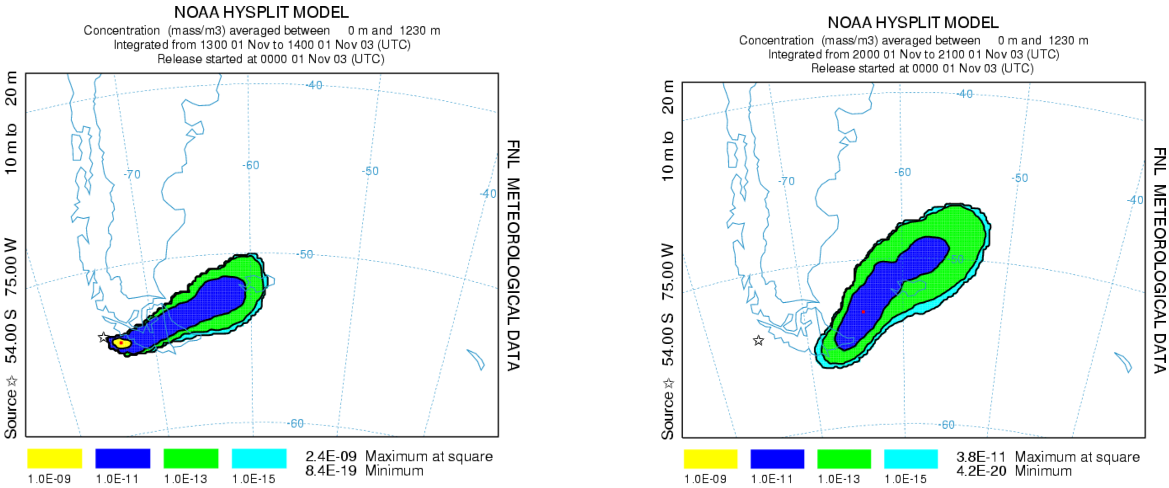
At an average outside air temperature of 5°C, for neutral atmospheric stability conditions, the height of the plume to shearing gives an effective release height of 1,200m.

The stricken vessel is assumed to approximately 100km off the west coast of Chile in the approach to Cape Horn at 54.000S 77.000W

The dynamics of the plume concentration and deposition fall-out are plotted using the NOAA HYSPLIT model and plume rise prediction is by Hotspot.[12] The NOAA plume development and ground dispersion results are available as dynamic .gif files, with the following summarising these:



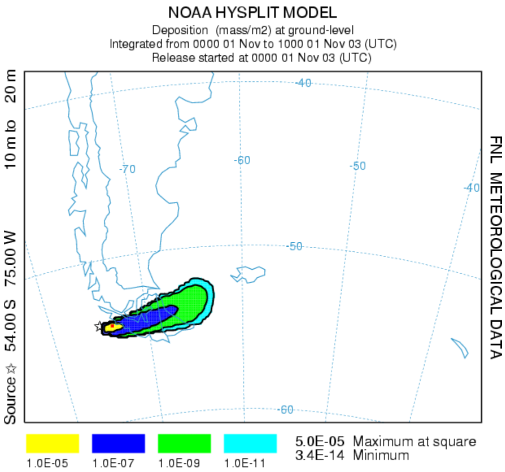
Plume Trajectories for a release centred at 54.00 S and 77.00 West – the location of the vessel is shown thus ★

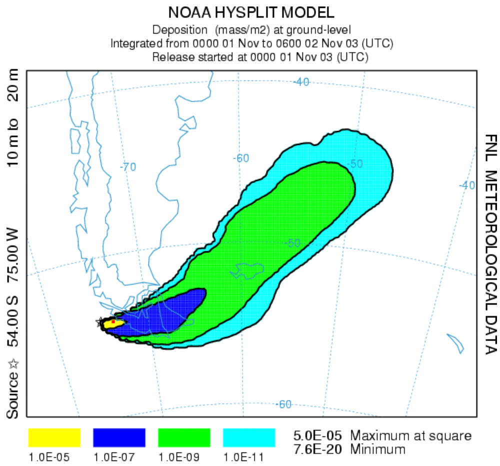


Development of the Airborne Plume: Above Left - 14 hours into the event, 3 hours after the release has ceased from the vessel located at the ★ . Above Right, with the plume expanding to the north-east 21 hours following the event onset. Airborne concentrations are given in 4 bands in Curies per cubic meter (1 Ci = 3.7 1010 Bq) which is significant for the first two (Yellow and Blue) bands, particularly if significant alpha-emitting radioisotopes (actinides) are present (which has not been analysed here.

12 NOSS HYSPLIT is the USD Air resources Laboratory air concentration and dispersive model and Hotspot is the Lawrence Livermore National Laboratory predictive software for release plumes.

The development of deposition or fall-out is:





Development of the Disposition: At 10 and 30 hours respectively. Units are Ci/m^2 with the first two bands (Yellow and Blue) being significant and, for permanently populated areas, decontamination would be required. Sea areas so contaminated would dilute and disperse, although sea creatures would be expected to register elevated levels depending upon the type of seabed and inter-tidal sediments, not considered here.

SUMMARY

This brief analysis of a seriously damaging fire incident on board the *Fret Moselle* is summarised as follows:

a) The analysis examines the dispersal and deposition of a radioactive release that results from a fire at sea. The fires at sea can be very severe events indeed that, on average, can burn for 20 or more hours, spreading from hold to hold, and within the confines of the ship's hull attaining very high temperatures. There published investigations and trials demonstrating that a severe ship fire at sea is sufficient to, first, rupture the flask containment and, second, further volatise the fuel within for release into the rising plume of the fire.

b) The single cargo hold design of the *Fret Moselle* is not entirely suited to the effective containment of a fire from the machinery space, spreading throughout the ship.

c) The onset of such a fire might be accidental, although following events of 11 September 2001 fire by terrorist act should not be entirely discounted. If, somehow, a terrorist group could take command of the *Fret Moselle*, the vessel might be manoeuvred to a position where the radioactive release would have the greatest human and/or economic impact. Unlike recent shipments of mixed oxide fuel (MOX) to and from Japan on armed and escorted PNTL ships, the *Fret Moselle* does not seem to have extraordinary security precautions on board.

d) The fraction of the source term adopted for the modelling (at 20%) might be considered by some to be too high, particularly when compared to the lower release fractions adopted by the nuclear industry for its modelling of the aftermath of accidents. However, there is very little published data of this type of wafer thin, low operating temperature (~50^{o}C) cermet (ceramic-metal) fuel. Its performance under extreme temperature conditions may be unfavourable, particularly when compared to the superior performance of uranium oxide fuels in commercial power reactor incidents.

Often the nuclear industry worldwide defends its claim for the safety of transport of radioactive consignments at sea on its record to date and on the safeguards provided by what, at first reckoning, seems to be a plethora of safety regulations.

Obviously, past performance is no portend of present and future safety and, moreover, the *Fret Moselle* is a newly registered vessel that has never transported such a hazardous radioactive cargo before. The safety and security regulations might well apply to those countries dispatching and receiving the cargo, the vessel itself may be IMO SNF II compliant and the fuel flasks be certified Type B as prescribed by the IAEA regulations, but what of the local communities in close proximity the locality of the release, here those around Cape Horn and the Malvinas (Falkand) Islands.

These communities may not be adequately prepared in terms of being notified sufficiently in advance of the vessel passing along their coastlines and, because of this, they may not have sufficient time, skills and/or resources to adequately plan for such an emergency from an external and uninvited hazard, and the international treaties on nuclear liability may fall far short in providing adequate compensation.[13]

In fact, at the recent IAEA conference on the transport of radioactive materials a number of national delegates (Peru, New Zealand, Ireland)[14] urged for prior notification and information on sea shipments for the purposes of their own emergency planning.

The dilemma here is that the coastal communities at risk are unable to put in place plans to safeguard themselves against a radioactive release, whereas the shipping nations, who do have the resources and knowledge, will not provide such measures because, it might be argued, to do so would admit to the inherent risk associated with the transportation of nuclear materials at sea.

[13] International Atomic Energy Agency International Conference on Safety in the Transport of Radioactive Material, IAEA Vienna, July 2003, Greenpeace International posted paper.

[14] Ibid – see Large, J H *Review of Conference Papers* and particularly papers CN-101/6 & 11 (Peru), CN-101/2 & 16 (Ireland), CN-101/4 (New Zealand) and CN-101/116 (Norway) on the effectiveness of anti-terrorism measures.