Attachment: E391_04

Consequences of an Attack on a Spent Fuel Shipment

This note examines the consequences of an attack on a shipment of spent HIFAR fuel being transported from Lucas Heights Science and Technology Centre to a port for loading onto a ship.

Discussion

An amount of work has been carried out in the US to date to examine the effects of an attack made against road and rail transport packages used for Light Water Reactor fuel. The work reported here takes the US work as a starting point, and considers the differences between it and the ANSTO situation in order to draw out those aspects of the attack that are important to the eventual source term and quantify the differences. The code PC COSYMA is then used assess the public health effects of the source term.

The principal differences considered are: the transport cask, the transport medium, and the type of fuel. The nature of the weapon used in the attack is assumed to be similar to that of the US case.

<u>Transport package</u>

The two US transport casks considered were a road type and a rail type. The road type is of a size similar to that used for the transport of spent HIFAR fuel, while the rail cask is considerably larger. The penetration of a High Energy Density Device (HEDD) will pressurise the inside of the cask. To a first estimate, the degree of pressurisation between the road cask and the HIFAR cask will be similar.

The construction of the HIFAR cask is lead surrounded by stainless steel. The US road cask is constructed of alloy steel surrounding depleted uranium. The HIFAR cask might therefore be considered 'softer' in terms of resistance to impact of the HEDD that the road cask. In practical terms, this would manifest itself by a greater likelihood of exiting of the HEDD from the cask (the road cask suffers entry but no exit of the HEDD). This would likely reduce the amount of damage to the spent fuel inside the cask, in that the HEDD would not ricochet around the inside of the cask. In this work, however, we shall assume that the HEDD enters but does not exit the HIFAR cask.

The result in both cases is that the pressurised blowdown of the cask following initial HEDD penetration might be expected to be similar.

<u>Transport medium</u>

Spent fuel in the US is transported in the dry state. In Australia, spent HIFAR fuel is also transported dry. The US work concentrated on dry fuel, as this maximised the amount of aerosol released from the cask. The work by Luna et al considers the Sandia work by Sandoval et al on a quarter-scale cask that included a water jacket. It was found that the source term was significantly lower, owing to the scavenging of aerosol particles by water droplets and mists. The water jacket of the Sandia tests may be considered to provide a limited source of water.

Type of Fuel

The US work considered spent Light Water Reactor fuel. This is made of $U0_2$, a brittle ceramic, which was found to shatter on impact by the HEDD and form a powder. This powder, owing to the energy absorbed in the impact, was found to contain a significant fraction of particles of respirable size. The crystalline nature of the fuel, in allowing significant energy absorption, also stopped the HEDD before it could ricochet against the back wall of the cask. The stiffness of the Zircaloy cladding of the LWR fuel also contributed to lateral damage of the fuel assemblies, further increasing the amount of spent fuel damaged.

In addition to the fragmentation aerosol produced by the brittle fuel, the US work also considered the effects of blowdown of the fuel pins. LWR fuel pins are pressurised to some 40 bar following irradiation. On failure of the pin cladding, the plenum gas blows down, taking with it the radioactive noble gases and volatiles that have accumulated in the gap over the course of irradiation. In addition to the blowdown source term, radioactive crud attached to the outside of the fuel pins can be spalled off by the impact, adding to the aerosol source term.

The fuel used in HIFAR is entirely different to that considered above. It consists of metallic uranium in an aluminium matrix bonded to aluminium cladding. This is the type of fuel considered by Miller et al. Compared to LWR fuel, it is exceedingly soft and malleable. In the event of penetration by a HEDD, it will not fragment but will instead tear. An amount of aerosol containing fission products will, however, still be produced, although to nothing like the degree seen for the LWR case.

The softer nature of the HIFAR fuel will not absorb the energy of the HEDD to the same degree as LWR fuel. The HEDD is therefore likely to travel further into the cask, with a greater potential for ricochet off the internal walls of the cask, further damaging spent fuel assemblies.

The lack of a plenum and external crud in the case of the spent HIFAR fuel limits the fission product release to that associated with the fuel matrix.

Calculations

In order to determine doses to persons downwind of the attack, it is necessary to estimate the source term arising from the attack. To estimate the source term and resultant doses, the problem is broken down into a number of pieces. These are:

- Radioactive inventory of spent fuel,
- Fraction of cask inventory formed into a respirable aerosol,
- Retention of respirable aerosol in the cask, and
- Atmospheric transport.

Radioactive inventory in the spent HIFAR fuel

The spent HIFAR fuel will have been decaying for some five to ten years before it is transported. All short-lived fission products will have decayed to essentially zero. Only the longer-lived actinides will be present, together with long lived fission products. Table 1 lists the radioactive elements considered in this assessment. The results are taken from work done by Hambley.

Fraction of Spent Fuel Aerosolised

While causing much damage to the spent HIFAR fuel in the cask, the aspect of the damage caused by the HEDD of most interest is the fraction of spent fuel formed into aerosol particles that are of respirable size (i.e. capable of remaining suspended long enough to enter human airways and become lodged there.)

Much of the US work is presented in terms of the fraction of cask inventory aerosolised. Because of the differences in fuel type, this is of little use here. Instead, use is made of the work carried out by Miller et al who looked at, amongst others, typical research reactor fuel. Taking 4 U-Al fuel plates, they fired a HEDD through them and determined the amount of respirable aerosol produced by collecting on cascade impactors. They then used the information so obtained to estimate fractional releases. In the work reported here, the base results are considered and applied to the HIFAR case.

Table B-6 of the Miller et al paper reports the cascade compactor results. For the two final tests (the first two were considered unreliable), the total U mass produced of aerosol of respirable size (taken to be 1 to 10 µm) is between 270 and 770 µg. In this work, it is assumed that 800 µg is the upper bound value, i.e. 200 µg per plate. This is to be understood as the impact of a HEDD produces a respirable aerosol containing 200 µg of uranium.

The spent HIFAR fuel consists of 4 fuel tubes. It is assumed that the HEDD penetrates the spent fuel completely, i.e. 8 ‘plates’, releasing some 1.6 mg of respirable aerosol. Because the spent HIFAR fuel is so malleable, it is assumed that 100 complete penetrations of fuel assemblies takes place, owing to ricochet effects. This value is considered very conservative for this analysis, as deformation would become more likely as the energy of the HEDD was reduced. The maximum total amount of respirable aerosol produced is thus 160 mg. Assuming 35 kg of U-235 in the cask gives a uranium loading of approximately 60 kg. This in turn leads to a value of fraction of respirable aerosol produced of 2.7×10^{-6}. To allow for uncertainties regarding the form of the HEDD and the mechanism by which it fragments malleable aluminium, the fraction is arbitrarily increased by a factor of 3 to 1×10^{-5}. This value is a factor of three below the worst-case value determined by Sandoval, and is consistent with the non-brittle fracturing behaviour of research reactor fuel. This fraction is applied to the inventory of radioactive material in the cask as shown in Table 1.

Retention in the Cask

All the US work considered dry cask contents. Retention of respirable aerosol would be expected, to a degree. However, the blowdown of the cask following initial penetration will likely remove most of the aerosol. Conservatively, therefore, no retention in the cask is considered. Table 1 shows the resultant source term of respirable aerosol to the environment outside the cask.

Atmospheric Transport

The code PC COSYMA was used to evaluate the doses to members of the public arising from the release of respirable aerosol. Given that the transport is quite likely to occur in the night, Pasquil 'F1' weather conditions were considered.

Results

A committed effective dose of 76μSv at 150 m was calculated. This is close to the computational limits to which the code will work 'close in'. Nearer to the source, actual plume meander can significantly affect doses. Other doses are shown below.

Distance downwind/ m	Dose/ μSv
200	73
500	35

The peak dose was made up of 50% inhalation and 50% groundshine. The dominant contributor to inhalation was Pu-238, while the dominant contributors to groundshine were Cs-137 and Cs-134. The latter two radionuclides have half lives of 30 years and two years respectively, while the former has a half life of 90 years.

Assuming nearby persons were removed soon after the attack and did not continue to receive the groundshine dose would result in a reduction of their committed effective dose to approximately 38 μSv.

The calculation assumed members of the public to be outside for the entire duration of the attack. At night, people could be expected to be in their houses. This would reduce the inhalation dose from 38 μSv to 19 μSv.

Members of the security services present at the time of the attack would likely retire to shielded positions and receive inhalation doses of the same order of magnitude as those mentioned above. Members of the emergency services attending after the event would arrive after the plume had passed over and would not be subject to long term irradiation by groundshine. Their doses would be less than an estimated 5 μSv, assuming that radiation protection personnel were present to supervise operations in terms of ensuring no resuspension of deposited particles.

Attachment: E391_04

Referenced Material

NUREG/CR 4447, *Radiological Source Terms Resulting from Sabotage to Transportation Casks,* Miller et al, 1986.

SAND 83 0196C, *An Assessment of the Safety of Spent Fuel Transportation in Urban Environs,* Sandoval et al, 1983.

SAND 99 0963, *Projected Source Terms for Potential Sabotage Events Related to Spent Fuel Shipments,* Luna et al, 1999.

ANSTO
25 September 2003

Attachment: E391_04

Table 1. Radioactive Materials Considered

Nuclide	**Core Inventory/ Bq**	**Amount made into a Respirable Aerosol/ Bq**	**Amount Released from Cask/ Bq**
u234	1.30E+10	1.30E+05	1.30E+05
u235	1.40E+08	1.40E+03	1.40E+03
u236	2.40E+09	2.40E+04	2.40E+04
u238	2.60E+07	2.60E+02	2.60E+02
np237	7.20E+08	7.20E+03	7.20E+03
pu238	2.20E+12	2.20E+07	2.20E+07
pu239	5.80E+10	5.80E+05	5.80E+05
pu240	5.70E+10	5.70E+05	5.70E+05
pu241	9.80E+12	9.80E+07	9.80E+07
pu242	7.00E+07	7.00E+02	7.00E+02
am241	2.20E+09	2.20E+04	2.20E+04
am242m	4.90E+07	4.90E+02	4.90E+02
am243	1.40E+08	1.40E+03	1.40E+03
cm243	3.75E+07	3.75E+02	3.75E+02
cm244	3.60E+09	3.60E+04	3.60E+04
cm245	6.90E+04	6.90E-01	6.90E-01
kr85	2.00E+13	2.00E+08	2.00E+08
cs134	3.00E+13	3.00E+08	3.00E+08
cs137	1.50E+14	1.50E+09	1.50E+09
sr90	1.40E+14	1.40E+09	1.40E+09
ru106	3.00E+12	3.00E+07	3.00E+07