Risk Assessment in Spent Fuel Storage and Transportation

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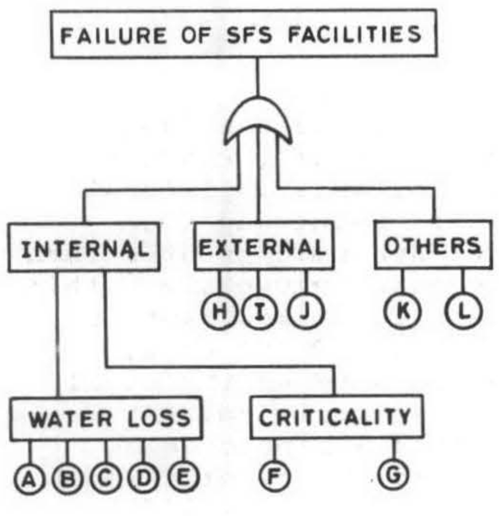
INTRODUCTION

Risk assessment in various stages of nuclear fuel cycle is still an active area of Nuclear safety studies. From the results of risk assessment available in literature, it can be determined that the risk resulting from shipments of plutonium and spent-fuel are much greater than that resulting from the transport of other materials within the nuclear fuel cycle. In India spent fuels are kept in Spent Fuel Storage Pool (SFSP) for about 240-400 days, which is relatively a longer period compared to the usual 120 days as recommended by regulatory authorities. After cooling spent fuels are transported to the reprocessing sites which are mostly situated close to the plants. India has two highlevel waste treatment facilities, one PREFRE (Plutonium REprocessing and Fuel REcycling) at Tarapur and the other one, a unit of Nuclear Fuel Complex at Hyderabad.

This paper presents the risk associated with spent fuel storage and transportation for the Indian conditions. All calculations are based on a typical CANDU reactor system. Simple fault tree models are evolved for SFSP and for Transportation Accident Mode (TAM) for both road and rail. Fault tree quantification and risk assessment are done to each of these models. All necessary data for SFSP are taken mostly from Reactor Safety Study, (1975). Similarly, the data for rail TAM are taken from Annual Statistical Statements, (1987-8) and that for road TAM from Special Issue on Motor Vehicle Accident Statistics in India, (1986). Simulation method is used wherever necessary. Risk is also estimated for normal/accident free transport.

SPENT FUEL STORAGE

A simple SFSP fault tree is shown in Fig. 1 below. Even though it is possible to construct big fault tree model to many of these individual units (e.g., Wignender, 1978), since here the idea is to obtain a conservative value for the TOP event probability, such simplifications have been made. Here the accidental release of radioactive materials (RAM) from the storage confinement or the failure of spent fuel facility is chosen to be the TOP (undesired) event. This fault tree has 12 basic events/units, with internal causes leading to fuel melting and the external causes to pool containment failure. The probabilities per reactor year to each of these events are also given in the same figure.



A	DROPPING OF CASKS	$Pr^{*} = 3 \times 10^{-6}$
B	HUMAN ERROR	10^{-3}
C	NO MAKE-UP WATER	10^{-3}
D	MAKE-UP WATER NOT RECOGNISED	10^{-5}
E	WATER LOSS FROM POOL	10^{-3}
F	DROPPING OF HEAVY ITEMS	3×10^{-6}
G	FUEL BECOMES CRITICAL	3×10^{-8}
H	TURBINE MISSILES	10^{-6}
I	TORNADO	10^{-9}
J	DAMAGE DUE TO SEIS. FORCES	3×10^{-8}
K	LIQUID WASTE STORAGE TANK FAILURE	10^{-2}
L	WASTE GAS STORAGE TANK FAILURE	10^{-2}

Pr^{*} - PROBABILITY OF OCCURANCE PER REACTOR YEAR

Figure 1. SFSP Fault Tree

SFSP fault tree is quantified as follows. Besides those basic events, the following three common cause failures are also identified in order to have better estimate for the TOP event probability : i) events A and F have common cause here as the failure of crane, ii) events B and E to the common cause of human error and iii) events G and J to seismic activity. Further, for any tree there are two ways of estimating the TOP event probability viz., Point Estimate and Random variable (Simulation) Evaluation. Point estimate approach requires highly accurate data and it is the sum of all the probabilities of individual events. Monte carlo Simulation or Random variable approach can be made, by assuming a distribution to the basic unit and by defining a range over which basic event probability is valid. Here the chosen distribution is log-normal as it is a suitable candidate for the reliability studies. The simulated results are shown in Fig. 2.

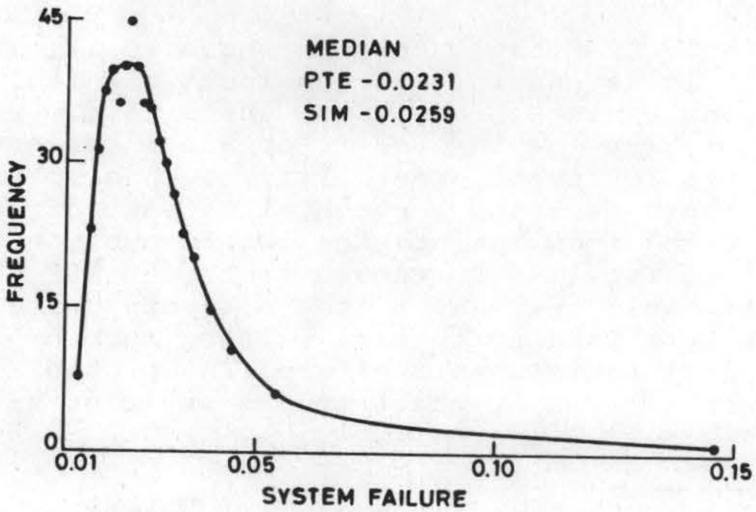


Figure 2. SFSP Failure Frequency Distribution

Further, the exposure risk to population is given by R=PfD where P is the probability of occurrence of an event/accident, f is the release fraction and D is total exposure to the public. In case of an SFSP failure, the radionuc-

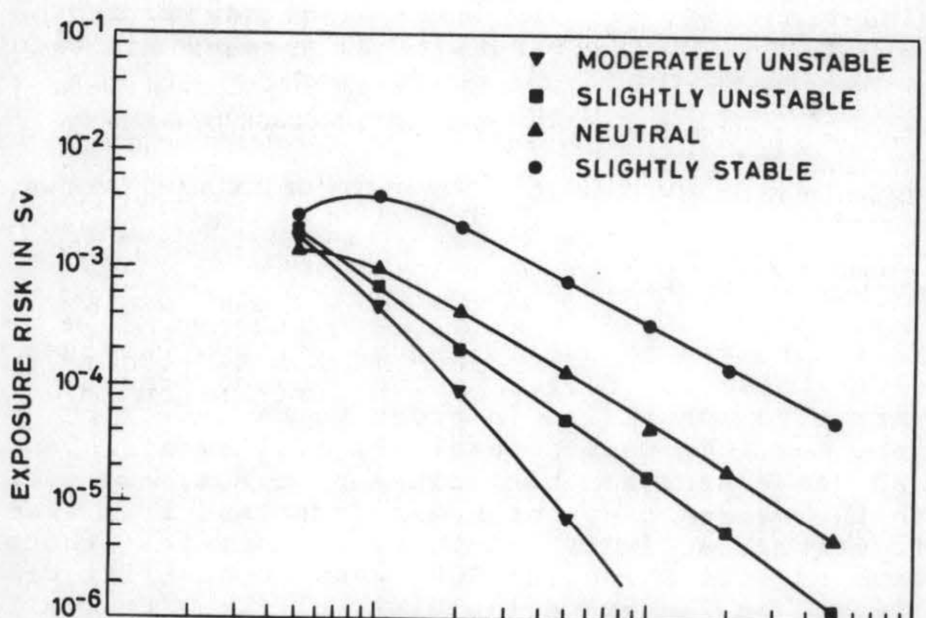


Figure 3. SFSP Failure Exposure Risk for Different Weather Conditions

lides will be released to the atmosphere either through stack or through containment structure failure. In order to estimate exposure dose, which is anyway dependent on the weather condition at the time of release, the spent fuel activity at that time must be known a priori. This comes from the fission product inventory studies, and much work has already been done (e.g., Chatterjee, 1980), which gives the activities of fission product over time after fuel discharge from reactor.

A Gaussian diffusion model is used to estimate the atmospheric dispersion of released RAM. All the dispersion coefficients required for the calculations and weather conditions used in this work are taken from Nuclear Power Plant Safety, Lewis, E.E, 1987. For SFSP failure assuming RAM release through a stack height of 31.0 meter , with a release fraction 20 % the exposure risks are estimated for four different weather conditions. The results are shown in Fig. 3. It is clearly seen that as the weather condition becomes more stable the risk increases.

TRANSPORTATION

ROAD

A CANDU reactor discharges 8 fuel bundles per day. At present in India spent fuels are transported from SFSP to reprocessing plant by road only. The major advant age of road transport is its flexibility as it is easy to reach from one place to another. However a truck or van has

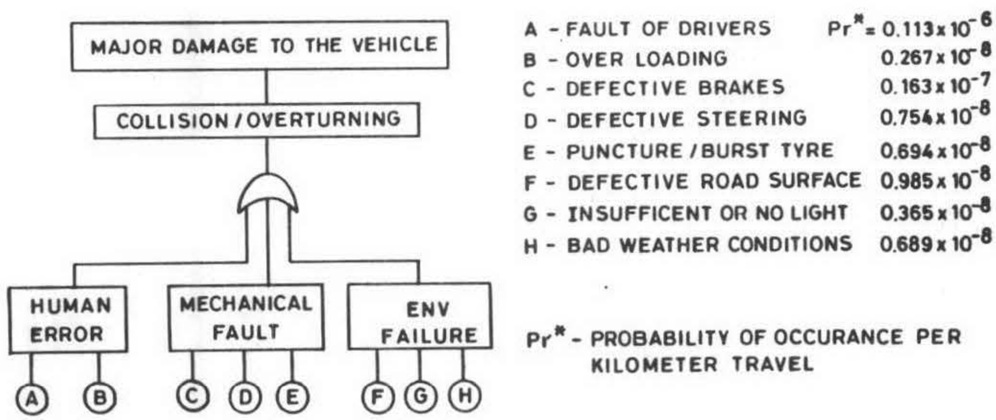


Figure 4. Road Transportation Fault Tree

limits on its load capacity. A fault tree for the road TAM is shown in Fig. 4. This model is in general applicable to all RAM shipments. Here only collision/overturning of the motor vehicle is considered to be the TOP event. Other kinds of accidents are neglected and similarly, 2 or 3 wheelers accidents are not accounted for.

This tree is basically classified into 3 broad categories namely Human error, Mechanical failure, and

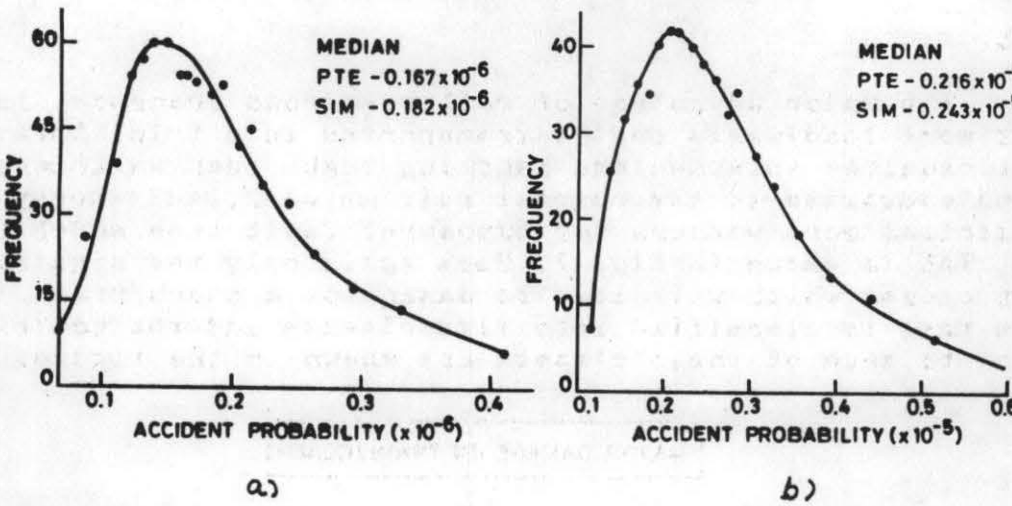


Figure 5. Transportation Accident Frequency Distribution a) Road b) Rail

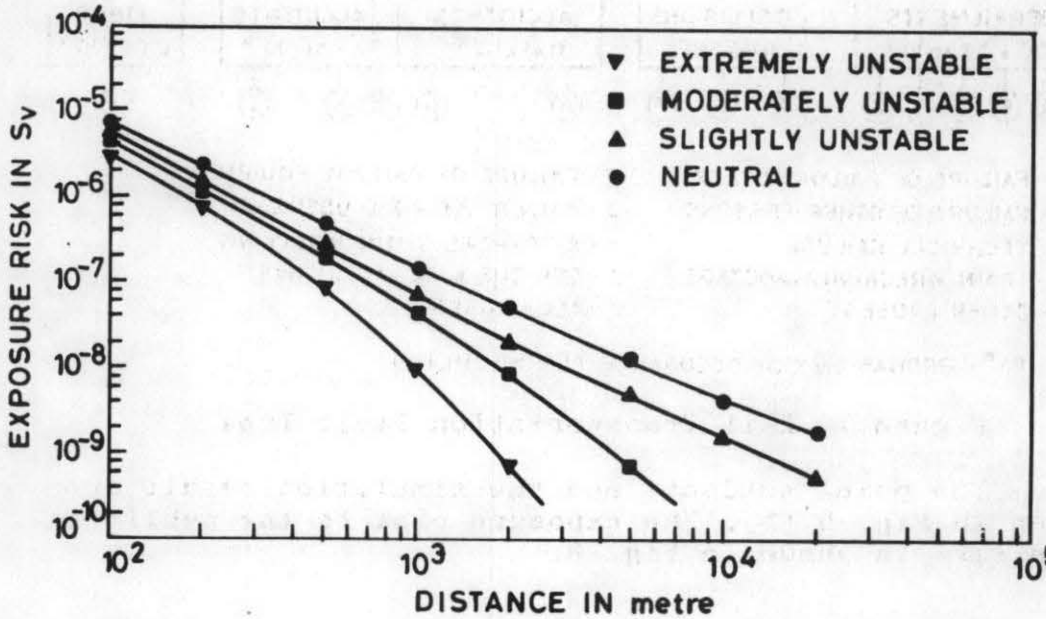


Figure 6. Road Transportation Accident Exposure Risks for Different Weather Conditions

Environment conditions. The basic events/cause leading to these categories and their probabilities are shown in the same figure. As in the case of SFSP here also point estimate and simulation results are obtained for the undesired event probability and are shown in Fig. 5 (a).

The exposure risk to the population in case of road accident for four different weather conditions is shown in Fig. 6. Here it is assumed that RAM is released at a height of about 3m from ground level with release fraction 20 %.

RAIL

The major advantage of rail over road transport is that more load/waste can be transported in a trip. However, rail requires intermediate handling tasks such as transporting radwastes to the nearest rail network, and therby subjecting more workers for exposure. Fault tree model for rail TAM is shown in Fig. 7. Here again only the significant causes which will lead to damage of a coach/train. This tree is classified into five classes and the contribution to each of these classes are shown in the figure.

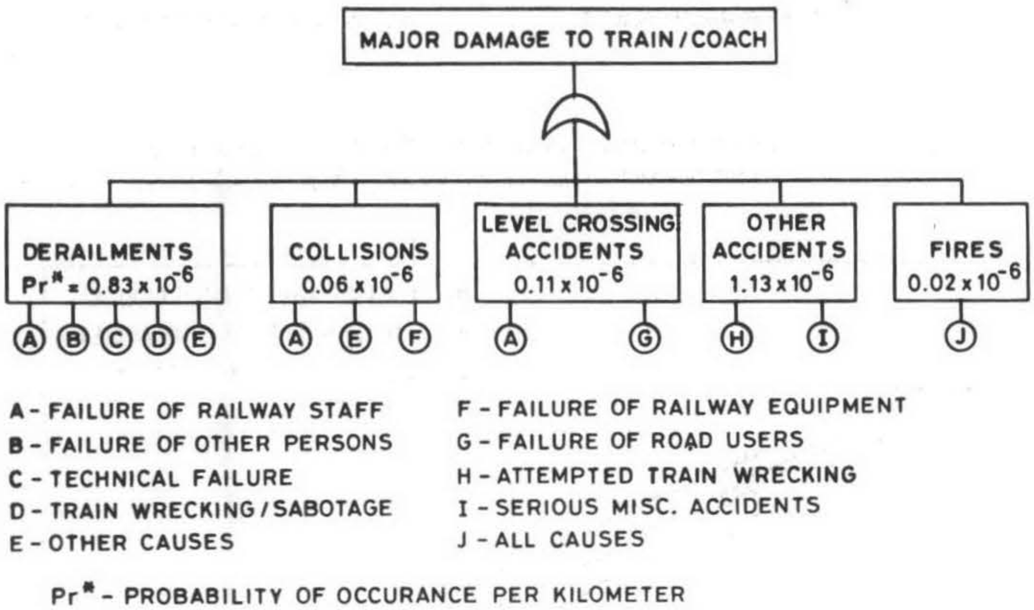


Figure 7. Rail Transportation Fault Tree

The point estimate and the simulation result are given in Fig. 5 (b). The exposure risk to the public in this case is shown in Fig. 8.

NORMAL TRANSPORT RISK

The risk estimate calculations for normal transport to a stationary population is done on the basis of the regulatory limit of 0.1 mSv/h at 6 ft from the surface of the vehicle carrying spent fuel. These calculations are similar to that of Spent Fuel Transportation on Highways-the Radioactive Dose to the Traffic, G. Yadigaroglu, 1975.

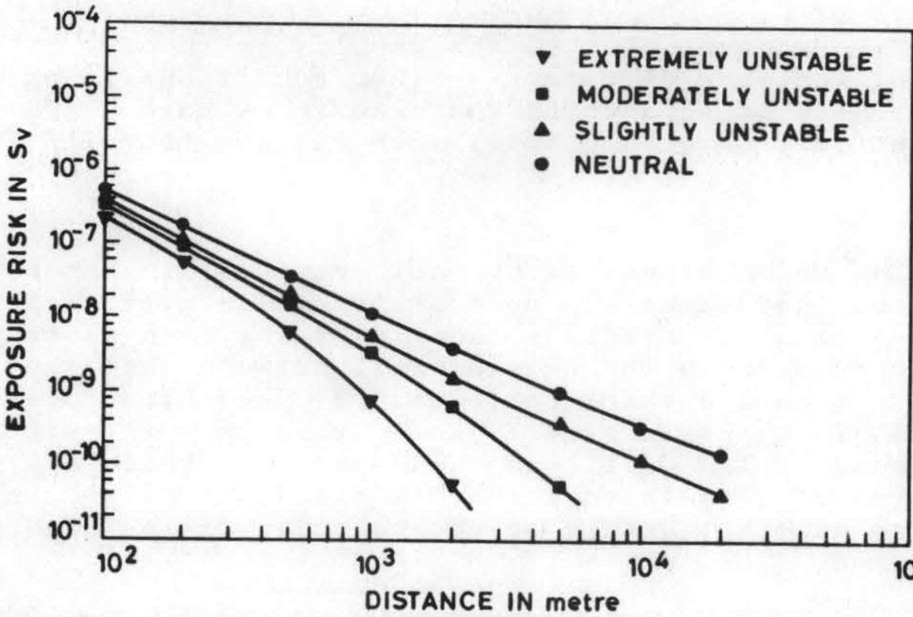


Figure 8. Rail Transportation Accident Exposure Risk for Different Weather Conditions

It is assumed that India's uniform population density is about 252 per square kilometer and that vehicle carrying RAM has a speed of 40 km/h. The cumulative population dose is estimated to be 2.203 x 10^{-8} man Sv per kilometer. Here the dose exposure to crew, material handlers are not included in the above calculations.

CONCLUSIONS

The results obtained in this work can be summarized as follows. A conservative exposure risk due to spent fuel storage pool failure for different weather conditions is estimated. Further refinement of this estimation requires more data for the Indian conditions.

The TAM risks for both road and rail transport are evolved. In India people living even along road side is quite high compared to other countries. So in case of an accident which is unlikely to occur because of limited shipments of spent fuels, the cumulative exposure dose will be enormous.

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