Probabilistic Safety Assessment for Radioactive Material Transport—A Perspective and Example Application from the UK

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INTRODUCTION

All the UK legislation to assure the safe transport of radioactive materials (RAM) is closely based on the IAEA Transport Regulations (IAEA 1985). In common with other countries where similar legislation is in place, the UK safety record for both the normal transport of RAM and accident situations is very good (Gelder et al. 1984, and Gelder et al. 1987). The UK Competent Authority places reliance on the IAEA Transport Regulations to ensure that this record is maintained (Department of Transport 1988).

What, then, are the reasons for undertaking Probabilistic Safety Analysis (PSA) for UK transport operations? Reasons are advanced in this paper and illustrated with an example of work recently undertaken.

TRANSPORT PSA CONTRIBUTIONS TO SAFETY

There are four main reasons for carrying out transport PSA, described in the following paragraphs.

Regulatory Review

Since their introduction more than 25 years ago, the IAEA Transport Regulations have been periodically reviewed. From time to time particular issues come to the fore as a result of transport experience or public concern. Examples include the air transport of plutonium, to which a Session of this Symposium is devoted, and the sinking of the Mont-Louis in 1984 leading to particular interest in uranium hexafluoride transport. PSA can provide one useful input to the assessment of such issues.

Risk Level Assurance

The IAEA Transport Regulations are essentially deterministic, in that minimum packaging requirements are specified appropriate to any RAM to be shipped. Safety is vested principally in these packaging requirements (with operational controls generally being of secondary importance).

As pointed out in the previous section, the UK regulatory authorities base the acceptability of RAM transport safety on compliance with the IAEA Transport Regulations. However, the regulatory authorities are increasingly using probabilistic safety criteria in the evaluation of the safety of major new fixed site industrial plant, including nuclear power reactors, in the absence of directly applicable historical experience. There is currently no suggestion that probabilistic criteria will become the basis for UK RAM transport safety assurance. However, it is useful to be able to show that operations conforming to the IAEA Transport Regulations do not lead to levels of risk in excess of criteria applied to fixed plant. RAM transport risks must be evaluated using PSA techniques to facilitate such quantitative comparisons.

The IAEA transport packaging standards are not explicitly set to meet probabilistic safety criteria, although assessments indicate their adequacy in doing so. The role of such criteria in the development of the Transport Regulations is currently the subject of debate.

Optimization

PSA enables the identification of the origins of the major contributions to the total transport operation risks. Decisions concerning possible changes to reduce risks may be based on the comparison of quantitative data for the risk reduction with any associated penalties. Optimization techniques are best developed for application to normal transport, but can also be applied to possible accident situations.

The scope for optimization in transport is in many cases rather limited, because of the high safety levels necessary to meet the IAEA Transport Regulations and other factors such as on site package handling.

Questions

The IAEA Transport Regulations provide a high degree of safety assurance, but RAM transport radiological risks cannot be completely eliminated. Safety questions arise through representative bodies and the media, and major new developments in the UK may be subject to the scrutiny of a Public Inquiry. A transport PSA can provide quantitative evidence to counter unnecessary concern.

AN EXAMPLE APPLICATION - WASTE TRANSPORT PSA

Background

UK Nirex Ltd has been set up by the UK nuclear industry to provide facilities for the disposal of solid intermediate level and low level radioactive wastes (ILW and LLW). Nirex is currently seeking to develop a single deep repository for the disposal of both ILW and LLW. Prior to the selection of a small number of sites for detailed investigation, a PSA was undertaken for the transport of ILW and LLW to three notional locations in different regions of the UK. At this early development stage there were clearly many uncertainties in the analysis input data. However, the aims were to establish a methodology, identify data requirements for future more specific studies, provide feedback on package design, make an initial estimate of likely risks and provide information for site selection studies.

Operation

The annual transport of about 40000 m^3 LLW and 15000 m^3 ILW from more than 20 principal arising sites was assumed for the assessment. A variety of standard packagings are being developed (Smith 1988) and more than 800 waste streams were identified. To simplify this assessment three examples which were expected to represent pessimistic radiological hazards were selected:

- irradiated fuel cladding swarf immobilized in cement in 500 litre drums (ILW)

- combustible plutonium contaminated material immobilized in cement in 500 litre drums (ILW)

- an operational LLW stream in 200 litre drums.

The ILW was assumed to be transported in re-usable containers designed to provide shielding and impact resistance for four drums. The LLW was assumed to be carried in specially designed 6 m ISO type freight containers with a capacity for some 60 drums.

Transport by road and rail were considered, the maximum allowable total road vehicle mass for unrestricted movements of 38 t being one factor in the choice of mode. In addition, one of the notional repository locations was an offshore island, necessitating sea transport.

The total approximate land transport distances for the three repository locations ranged from 5 to 10 million package km per year.

Normal Transport

The IAEA computer code INTERTRAN (Ericsson and Elert 1983) has been reviewed by the Safety and Reliability Directorate (SRD), compared with other assessment methods, and UK specific input data have been prepared. It is considered by SRD to provide adequately accurate estimates of normal transport dose.

Using best estimate package surface dose rates, the total public collective dose due to all waste transport to the repository was evaluated,using INTERTRAN, to be in the range 0.5 to 1.2 man Sv a^{-1} (corresponding to 0.006 to 0.015 latent cancer fatalities per year), depending on the repository location. This may be compared with the "basic unavoidable" collective dose from radiation of natural origin (cosmic, terrestrial γ and internal radiation excluding radon and thoron) to the public along the waste transport routes of approximately 2000 man Sv a^{-1}.

Accident Conditions

INTERTRAN has been considered by SRD for application to accident conditions, but it is judged that alternative methods are more reliable. Consequently the frequencies of serious transport accidents, waste package responses to accident conditions and the radiological consequences were assessed and used to evaluate accident risks.

Accident Probabilities

Base probabilities of

rail derailment : 3.2×10^{-7} (wagon km)$^{-1}$

road accident : $1.0 \times 10^{-6} - 1.5 \times 10^{-6}$ (vehicle km)$^{-1}$

were derived from a review of UK historical experience based data. Both probabilities include minor accidents involving no human injury, and packages designed to the IAEA Transport Regulation requirements will withstand most accidents intact. Event tree methodology was applied to the base accident frequencies to derive the probabilities of accidents sufficiently severe to have radiological consequences.

Potential accident scenarios considered included road-rail transfer crane failure, falls from bridges, impacts with another train or road vehicle on the same or on an adjacent line or carriageway, impacts with lineside or roadside objects, overturns, and fires involving lineside or roadside stores of flammable materials, or trains or road tankers carrying flammable products.

The best available probability data for parameters such as hazard occurrence, impact speed, impact surface hardness and fire duration were employed. Where necessary the data were supplemented by cautious judgement, resulting in conservative evaluations.

The following package containment failure probabilities were derived in this way:

	LLW package	ILW package
rail (million wagon km)$^{-1}$	0.27	0.0065
road (million vehicle km)$^{-1}$	0.4 - 0.48	0.011 - 0.021

Ship serious casualty and total loss frequencies of 0.04 and 0.003 a^{-1} respectively were used.

Accident Source Terms

It was assumed (since packaging development was at an early stage) that the packages would fail under accident conditions just more severe than the minimum IAEA Transport Regulation requirements, ie IP-2 requirements for LLW packages and Type B requirements for ILW packages. In practice, final designs are likely to have significant margins beyond these minimum requirements.

Some experimental and theoretical data were available to derive respirable release fractions for the ILW streams under impact and fire accident conditions. Data available from literature were used for LLW. In all cases where uncertainty existed a conservative interpretation was drawn. Release fractions in the range 10^{-5} - 1 were derived, depending on the nature and severity of the accident conditions, and in some cases on the radionuclide.

The radionuclide inventories and release fractions for the example waste streams were applied to all the waste to be transported. This was not expected to underestimate the total risk.

Following an accident at sea in coastal waters it is likely that all packages will be recovered without significant loss of RAM. However, for illustrative purposes it was assumed that the entire contents of a package of the most active waste were released and dissolved.

Accident Consequences

The radiological consequences of each atmospheric release were evaluated using the CRACUK computer code (Ritchie et al 1984, and Nixon and Egan 1985). CRACUK calculates the downwind dispersion of a released plume of radioactivity and resulting exposures. External exposure from airborne and deposited material, and internal exposure from inhalation and the consumption of contaminated foodstuffs were considered. No mitigating actions to reduce doses were assumed following a release. Individual doses as a function of downwind distance for specified weather conditions were calculated. In addition, societal health detriments in terms of probability distributions of the numbers of consequences in the exposed population were obtained using meteorological data.

The doses for hypothetical exposed individuals would not exceed 1 mSv under average weather conditions at distances more than several hundred metres to about 7 km downwind of the release, depending on the waste stream and accident severity. The expectation value of the distribution of latent cancer fatalities, conditional upon the release having occurred, varied from about 10^{-5} to 34, depending upon the waste stream, accident severity and population density. Of course these consequences must be considered with the associated low accident probabilities to assess risks, as shown in the following section.

The radiological consequences of a release in sea-water were evaluated using the computer code COLDOS (MacKenzie and Nicholson 1987). The dispersion of activities through inter-connected sea compartments, and uptake by and remobilisation from the sea bed were modelled. Exposures via the consumption of contaminated seafood and external irradiation from contaminated beaches were considered. The total time integrated collective dose to the UK population from a release in the Irish Sea was calculated to be 11 man Sv (compared with the annual UK population "basic unavoidable" natural origin dose of about 50000 man Sv).

Accident Risks

The maximum radiological risk to an individual along the waste transport routes was calculated from

$$R_I = \frac{2c}{\theta L} \sum_i \sum_j F_i D_{i,j} (r_{j+1} - r_j)$$

Where c is the risk factor, θ is a meteorological factor for wind direction, L is route length, F_i is the frequency of accident scenario i and $D_{i,j}$ is the dose to an individual at the route centre-point from accidents occurring between r_{j+1} and r_j. R_I was evaluated to be about 2×10^{-9} a^{-1} for all notional repository sites. This figure may be compared with an individual risk value of 10^{-6} a^{-1} generally regarded as broadly acceptable provided benefits accrue and proper precautions are taken (Health and Safety Executive 1988).

The expectation value for the number of radiological fatalities was calculated from

$$R_E = c \sum_i \sum_k F_i P_k D_{i,k}$$

where P_k is the population density probability and $D_{i,k}$ is the dose received. R_E was evaluated to be about 0.0008 a^{-1} for all notional repository sites. This may be compared with the expected number of non-radiological fatalities (associated with traffic accidents and unrelated to the nature of the material being carried) of 0.2 - 0.4 a^{-1}. Thus, referring to the expectation value for normal transport fatalities derived earlier, it can be seen that normal transport dominates the radiological risk, but comprises only a few per cent of the total (including non-radiological) transport risk.

Societal risk criteria have not been generally accepted for use in the UK, but 10^{-6} a^{-1} has been suggested as a tolerable frequency for all accidents at a nuclear power reactor leading to 100 fatalities (Health and Safety Executive 1988). The assessed waste transport risk was below this value.

Overview

The waste transport PSA, conducted quite early in the repository and packaging development programmes, provided input to the programmes, for example,

- the assessed risks are very low in relation to acceptability criteria and comparative data, and are expected to prove to be pessimistic
- relative risk differences between notional repository sites are small, particularly in relation to calculation uncertainties.

Recent Developments

UK Nirex Ltd has recently announced two potential sites for a deep repository. It is intended to assess aspects of waste transport risk to these sites in more detail, and to assess further the relative contributions to transport risks from the spectrum of waste streams.

DISCUSSION

SRD experience of undertaking PSAs for RAM transport indicates that operations conducted in accordance with the IAEA Transport Regulations have very low associated risk levels, compared with available risk criteria and comparative data.

There is scope for improvement in the transport PSA techniques used in the UK, particularly to enhance efficiency rather than accuracy. For example, the use of very sophisticated dispersion codes designed for fixed plant calculations represents a level of detail not warranted for most transport assessments. It is believed that, at least for UK conditions, undue effort should not be directed towards trying, for example, to differentiate between specific routes. It is considered that significant uncertainties (in, for example, release fractions or exposed populations, which may be route specific) are likely to remain, and assessed differences in risk corresponding to different routes in the UK are often not large in comparison.

PSA techniques are useful in underpinning the Regulations, and in providing quantitative information as an input to their continued development. However, it is believed that other factors are also important in this development. For example, Type B packages are required to withstand a very high fraction of potential accident conditions. Reliance only on risk criteria would not necessarily lead to the achievement of this requirement since, for example, if the accident frequency is very low the failure fraction can be higher. There are additional difficulties in defining individuals, populations and operations for comparison of risks with fixed plant and other data. It is thus difficult to see risk criteria as the sole basis for RAM transport safety regulation in the near future. Nevertheless, it is helpful to pursue the establishment of links between the essentially deterministic basis of the Transport Regulations and the probabilistic evaluation commonly used in other fields.

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