# The Safety Case for Transporting Spent Nuclear Fuel

**Charles Kros [1], Dr Ruth Weiner [2]**

[1] NECSA, PO Box 582, Pretoria, 0001, South Africa [2] Sandia National Laboratories, PO Box 5800, MS 0718 Albuquerque, NM, 87105-0718, USA

**Abstract**

The transportation safety case for transporting spent nuclear fuel is a requirement for licensing. It has both qualitative and semi-quantitative aspects. The qualitative aspects include transportation regulations, radiation dose limits, role of the transportation package in transportation, transportation package certification process, training, emergency response, the performance of the transportation package in accidents, and the evaluation of past transportation accidents. The quantitative aspects support the qualitative descriptions. Radiation doses accrued by members of the public and by workers are calculated using the code RADTRAN. Dose from both routine, incident-free highway transportation and from highway transportation accidents are part of the safety case and will be compared with both background doses and the regulatory safety criteria.
The radiation doses from routine transportation are calculated for:

- The maximally exposed member of the public.
- Doses to vehicle escorts.
- Doses to vehicle crew

Collective doses to populations are calculated for representative routes. Collective dose depends on the number of people affected as well as on the extent of the radiation from the source to which reference groups are exposed. Accidents involving loss of gamma shielding and loss of confinement integrity are discussed, as are accidents in which there is no impact on the cargo.

Keywords: transport safety assessment, spent fuel transport, RADTRAN, radiation dose, collective dose

## INTRODUCTION

This paper discusses the experience gained in licensing the transporting of spent nuclear fuel through a spent nuclear fuel repatriation project in South Africa during 2010. The paper will focus on the requirements of a transport safety case and demonstrate how this was applied in the case of this project.

The National Nuclear Regulator (NNR) is the competent authority responsible for the regulation of transport of nuclear material in South Africa. As such, the safety case for the transporting of spent nuclear fuel needs to be submitted to and approved by the NNR prior to the transport action taking place.

## DEFINING THE SCOPE OF THE ASSESSMENT

The NNR requires through local legislation and in terms of the IAEA transport regulations [1] for the operator to demonstrate compliance to safety criteria.

A graded approach is applied where the transport of small quantities and ad-hoc transport actions can demonstrate compliance through simplified methods. Typically for excepted packages, extensive use is made of the IAEA Advisory Material [2] and more focus is placed on normal conditions of transport, commensurate with the risk.

The NNR requires complete safety cases for the transport of radioactive material to be prepared and submitted for approval. Transport safety cases need to address the risks associated with normal as well as accident conditions of transport. It was recognised that the transport of spent nuclear fuel was regarded to be not only a large quantity of material but also a sensitive issue for which the regulator had to ensure the safety of the public. Therefore a complete safety case was prepared.

## QUALITATIVE ASPECTS

The safety case contains aspects of a qualitative nature most of which is very prescriptive in its requirements. In South Africa requirements are a combination of local and international requirements:

- Transportation regulations [1] where a graded approach is applied, for example the content limits for packages, package design criteria,
- Radiation dose limits for exposure of members of the public, set in local legislation but aligned with the recommendations of IAEA Basic Safety Standards [3],
- Role of the transportation package to ensure safety by means of the transportation package certification process which should adequately demonstrate compliance throughout design, manufacture and maintenance,
- Procedural arrangements including those for training, emergency response, preparation, consigning, loading, carriage, in-transit storage, unloading and receipt of radioactive material and packages,
- Security provisions as required by local and international authorities.

## QUANTITATIVE ASPECTS

The safety case contains quantitative aspects which supports the qualitative descriptions and facilitates the demonstration of conformance.

The common denominator is the radiation doses accrued by members of the public and workers during the transport operation. The Transport Regulations [1] defines three general severity levels:

- Routine conditions of transport (incident free);
- Normal conditions of transport (minor mishaps); and
- Accident conditions of transport.

The consequence of these severity levels (or conditions of transport) needs to be quantified for the transport operation. This was achieved by the use of the RADTRAN computer model developed by Sandia National Laboratories.

RADTRAN 6.0 [4] is an internationally accepted program and code for calculating the risks of transporting radioactive material both deterministic and probabilistic. Almost all input parameters are user-defined, therefore the user needs a certain familiarity with the appropriate values and the use of the programme. A simplified diagram of the code structure is given in Figure 1.

Through a collaborative agreement between the South African and US governments, a capacity building programme was launched to equip South African analysts in RADTRAN to perform this quantitative assessment as part of the licensing requirements (safety case).

The output of the code is highly dependent on the selection of appropriate input parameters. Much reliance was placed on default parameters [4] and internationally available studies [5]. Notwithstanding, the challenge of any computer model is the balance between realism and conservatism.

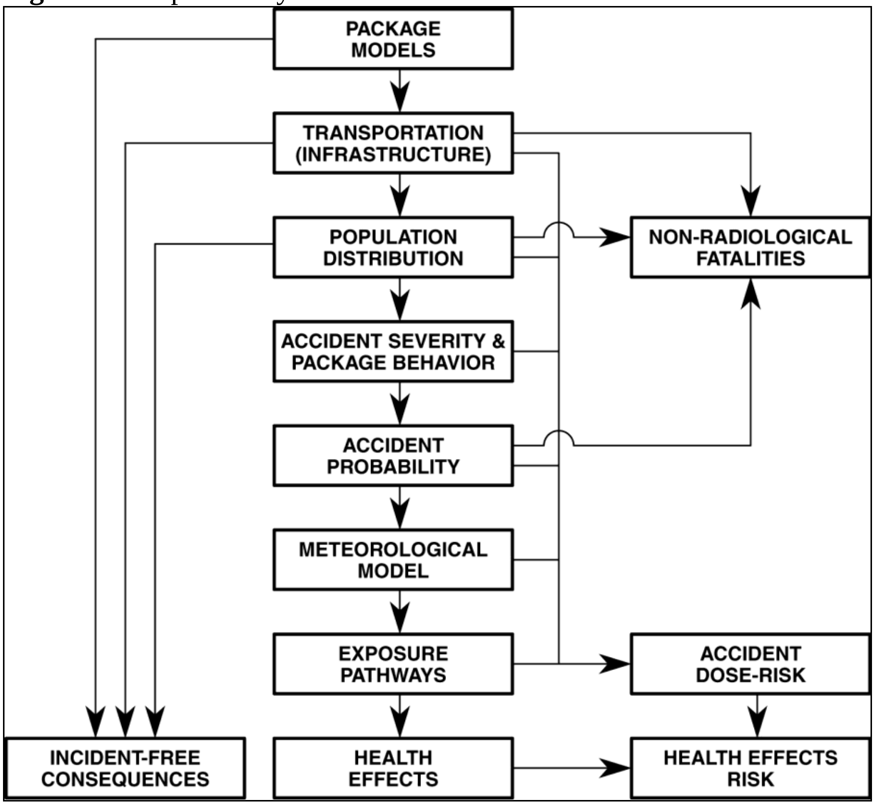
## ROUTINE TRANSPORT DOSES

Risks associated with routine conditions (incident free) of transport are limited to external exposure scenarios. The radiation dose rates for spent fuel shipments are measured before each shipment and kept within regulatory limits. The radiation dose from this external radiation to any member of the public during routine transportation, including stops, is barely discernible compared to natural background radiation. Principally, since no accidents are anticipated, no loss of any radioactive material and therefore no contamination is anticipated.

Exposure scenarios are limited to:

- Workers involved in the transport operation (drivers, handlers) and
- Members of the public in the vicinity of the operation or on route.

**Figure 1**: Simplified layout of RADTRAN code structure




Occupants of vehicles that share the route with the radioactive shipment also receive a radiation dose from the spent fuel cask. The collective dose to occupants depends on the average number of occupants per vehicle and the number of vehicles per hour that pass the radioactive shipment in both directions.

Any route can be divided into as many sections as desired for dose calculation; e.g., the dose to residents of a single house or city block. However, as a practical matter, routes are divided into rural, suburban, and urban segments according to the population per square kilometre (population density).

Given the complexity of calculating doses from for example moving vehicles, RADTRAN provided a suitable solution.

Input parameters for routine conditions of transport in RADTRAN are:

- Package external dose rate, which can either be the limits of the Transport Regulations (conservative) or actual measured/modeled dose rates;
- Crew details, ie number of crew, distance from package, shielding factors;
- Vehicle and package dimensions, for use in calculating exposure distances using inverse square law formula for handlers;
- Vehicle speeds to calculate exposure times from moving vehicles;
- Vehicle external dose rate for dose calculations;
- Route characteristics, ie distances, population densities (RADTRAN assumes the exposed population is in a 800 meter wide band on either side of the route), vehicle densities, persons per vehicle;

- Stop characteristics for exposure scenarios during stops at re-fuelling, compulsory stops, etc;
- Handling characteristics for exposure scenario during handling (normally occupationally exposed individuals).

RADTRAN calculates the doses assuming a probability of 100% and the results is normally a very small external radiation dose, presented as:
Results of such accidents are presented in the following forms:

- Collective external dose to residents along route;
- Collective external dose to public at stops;
- Collective external dose to urban non-residents;
- Collective dose to occupants of vehicles sharing route;
- Occupational external doses; and
- Maximum individual in-transit dose.

**TRANSPORT ACCIDENT DOSES**
The calculation of risks associated with transport accident is more complex. Given that the deterministic doses might exceed the criteria due to over-conservatism in assumptions, RADTRAN provides for the probabilistic assessment of these doses.

The different types of accidents that can interfere with routine transportation of spent nuclear fuel are:

- Accidents in which the spent fuel cask is not damaged or affected.
    - Minor traffic accidents ("fender-benders," flat tires), resulting in minor damage to the vehicle. These are usually called "incidents."
    - Accidents which damage the vehicle and or trailer enough that the vehicle cannot move from the scene of the accident under its own power, but which do not result in damage to the spent fuel cask.
    - Accidents involving a death or injury, but no damage to the spent fuel cask.
- Accidents in which the spent fuel cask is affected.
    - Accidents resulting in loss of lead gamma shielding but no release of radioactive material.
    - Accidents in which there is a release of radioactive material.

Radioactive materials released into the environment are dispersed in the air, and some deposit on the ground. If a spent fuel cask is in a severe enough accident, spent fuel rods can tear or be otherwise damaged, releasing fission products and very small particles of spent fuel into the cask. If the cask seals are damaged, these radioactive substances can be swept from the interior of the cask through the seals into the environment. Release to the environment requires that the accident be severe enough to fail the bolts that hold the cask lid, dislodge the lid, fail the seals, damage the fuel rods, and release the pressure in the rods. There must be positive pressure to sweep material from the cask to the environment. Even if the bolts and seals fail, if the fuel is in a closed canister in the transportation cask, no radioactive material will be released.

When material is swept from the cask and released into the environment, it is dispersed by wind and weather. The dispersion is modelled using the accident model in RADTRAN 6, which is a Gaussian dispersion model. The release would be at about 1.5 meters above ground level, since the cask is sitting on a truck or railcar. The gas sweeping from the cask is warmer than ambient, so that release is elevated. The maximum air concentration and ground deposition are 21 m downwind from the release. The dispersion was modelled using neutral weather conditions (Pasquill stability D, wind speed 4.7 m/sec). It was repeated using very stable meteorology (Pasquill stability F, wind speed 0.5 m/sec) but the difference was negligible, because of the relatively low elevation of the release. The maximally exposed individual would be located directly downwind from the accident, 21 meters from the cask.

Input parameters for accident conditions of transport are:

- Radionuclide inventory which, for spent fuel, can be very elaborate thus requiring a screening analysis to determine most important radionuclides based on relative dose contribution to be included;
- Accident rate (route characteristic) similar to routine conditions of transport but includes accident statistics and land farming fractions;
- Accident specific parameters such as the conditional probability of accident (severity for Type B containers) obtained from available studies [5], release, aerosol, respirable fractions, particle settling velocities;
- Meteorological parameters in case of an accident which fortunately provides for the selection of worst weather conditions (stability class) in the absence of known weather conditions.

Provided that the parameters were selected appropriately, the output of these calculations will yield results for the various kinds of accidents possible for example accidents involving a release and/or dispersion of material. Results of such accidents are presented in the following forms:

- Number of expected accidents (per link);
- Collective dose and/or population risk from inhalation, resuspension, groundshine and cloudshine;
- Maximum dose and/or risk for individual;
- Doses and dose risks per radionuclide and
- Critical group doses and dose risks

Additional information available in RADTRAN and outside the scope of this paper is a loss of lead shielding (LOS) model, an economic model and a recently added uncertainty analysis capability.

## INTERPRETATION OF RESULTS

The safety case presented to the competent authority needs to include the aspects addressed in this paper.

The safety case for the repatriation of spent fuel from South Africa included all the required aspects including a cask validation report, procedures, detailed assessments of the actions in the work procedures and a complete transport safety assessment.

The transport safety assessment was performed using RADTRAN computer code and the most important outcomes are summarised:

- The radionuclide screening assessment confirmed the 10 most important nuclides would be representative of >99.9% of the radiological impact;
- The spent fuel was ‘old’ (over 26 years since removal from core) and significantly less material were loaded into the casks than it was designed for;
- Doses from routine conditions of transport were extremely low (as a result of the low activity of the spent fuel) with the maximum individual in-transit dose calculated to be less than 3.0E-03 Sv;
- Notwithstanding the availability of a probabilistic module in RADTRAN, it was possible to demonstrate deterministically (assuming a probability of 1 for the accident to occur) compliance to dose criteria for accident conditions. The explanation for this is the low activity of the spent fuel as a result of its age.

## CONCLUSIONS

The safety case for the transport of spent fuel has several aspects for which compliance to regulatory requirements needs to be demonstrated.

The qualitative aspects are mostly administrative in nature. The quantitative aspects support the qualitative aspects to demonstrate compliance.

Through the use of the RADTRAN computer code it was possible to demonstrate that for normal and accident conditions of transport the doses and risks were extremely low and in compliance to regulatory requirements.

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