RISK ASSESSMENT WITH INTERTRAN FOR A SUBSET OF TRANSPORTS OF RADIOACTIVE MATERIALS IN THE FEDERAL REPUBLIC OF GERMANY

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Abstract

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An important subset of all transports of radioactive materials are those by rail. All transports in one year (1983) have been analysed with the aid of the computer code INTERTRAN, supplied by the IAEA to Member States in 1983. The resulting collective radiation exposure to different subgroups of the public and of railway workers has been determined. Work was concentrated on the derivation of well founded input values in order to obtain meaningful results. The values adopted are discussed. Finally the calculated radiation exposure to railway workers is compared with independent estimates of the Federal German railway authorities on the basis of parameters such as sojourn times, exposure distances, etc. The comparison indicates that the results presented should form a reasonable basis for a comparison of health impacts from incident-free transports of radioactive materials and from transports involving accidents.

1. INTRODUCTION

The computer code INTERTRAN [1] has been made available by the IAEA to Member States since 1983. It is a system for assessing the radiological impact from transporting radioactive materials. The computer code is to a large extent based on the RADTRAN II code developed at Sandia National Laboratories [2], but represents a more internationally oriented version suitable for application by many users. The INTERTRAN program can separately handle incident-free, i.e. normal case, transports and transports involving accidents. The results of the code are expressed in quantities related to the risk associated with an annual set of transports. For incident-free transport the resulting collective dose for different subgroups of the population is calculated. For transports involving accidents individual and population doses are calculated for every accident analysed and the annually expected number of health effects (early fatalities, early morbidities, latent cancer fatalities and genetic effects) resulting from a set of transports determined.

It is appropriate to emphasize that a clear distinction between the incident-free part and the accident part of the computer code INTERTRAN has to be made. For the incident-free case exposure of persons results from external radiation originating from radioactive material within the package and therefore the modelling of the resulting radiation exposure to different population sub-groups is fairly straightforward. In evaluating the radiological risk associated with transport accidents, modelling is far more complex since parameters such as accident rates, associated mechanical and/or thermal impact on packages, package response and release fractions dependent on material behaviour have to be determined. In addition, atmospheric dispersion of the material released has to be modelled and the resulting radiation exposure from different pathways to be evaluated. Therefore, in order to obtain meaningful results a large number of parameters have to be carefully determined.

The INTERTRAN code has a number of advantages:

(1) It is used in many countries and there is therefore the possibility of comparing the results of different users on the same basis, i.e. with the same modelling;

(2) The user is not deflected by code development work but can devote his efforts to determining parameters and data, which is essential in order to obtain meaningful results;

(3) Since INTERTRAN supplies default values for almost all parameters used in the program a gradual replacement of the parameters is possible as the analyst proceeds in determining parameters more appropriate to the special conditions of transports analysed or improved values from measurements and experiments.

2. SUBSET OF TRANSPORTS ANALYSED

The results of an assessment with the aid of INTERTRAN of radiation exposure associated with incident-free transports of radioactive materials by rail in the Federal Republic of Germany is presented below. All transports by rail for the reference year 1983 as summarized in Table I are analysed. The information relating to mean transport distances and mean dose rates at a distance of 1 m are also based on statistics from the railway authorities. Emphasis will be placed on the derivation of parameters used by the code.

3. INPUT PARAMETERS – INCIDENT-FREE CASE

A number of input parameters important for resultant radiation exposure have to be supplied by the user; alternatively, default values can be used. The derivation of values adopted for the analysis is discussed in the following subsections.

TABLE I. TRANSPORT OF RADIOACTIVE MATERIALS BY RAIL IN THE FEDERAL REPUBLIC OF GERMANY IN 1983
(1 Ci = 37 GBq)

Type of shipment	Number of wagons	Mean distance (km)	TI (mrem/h at 1 m)
UF_6 (natural or enriched, <5 Ci)	89	375	0.37
UO_2 or U_3O_8 powder (natural or enriched)	8	375	0.86
Fresh fuel elements	25	375	1.95
Spent fuel elements (≤13 MCi)	89	375	6.7
Radiation sources (≤2×10^5 Ci)	37	375	2.4
Uranium ore or concentrates (0.1–8.5 Ci)	436	375	1.1
UF_6 (depleted)	36	375	0.86
Low level waste (e.g. 200 L drums)	56	375	3.6
Piece goods (mean weight 90 kg)	Packages 1900	450	0.8
Goods shipped by express (mean weight 9 kg)	Packages 16 000	400	0.6

3.1. Population zones

A 795 km long railway route within the Federal Republic of Germany has been analysed in detail with respect to population density in a 1 km wide corridor on either side of the transport route[1] The data are summarized in Table II and indicate how the input parameters – mean population density in the three population zones and fractional part of transport route assigned to population zones – have been derived.

It is interesting to note that for the railway route analysed (from the Stade nuclear power plant near Hamburg via the Ruhr area to Forbach near Saarbrücken) an average population density of 1104 inhabitants per square

[1] The data on population densities and the fractional distribution in population density intervals were supplied by GUW – Gesellschaft für Umweltforschung mbH, Aldenhoven, Federal Republic of Germany.

TABLE II. DISTRIBUTION OF POPULATION DENSITIES ALONG SELECTED RAILWAY ROUTE (Stade to Forbach, 795 km) AND DERIVED INPUT VALUES FOR INTERTRAN

Result of population density analysis along railway route			Derived input for INTERTRAN		
Range of population density (km^{-2})	Fraction of route (%)	Average population density (km^{-2})	Assignment to population zone	Fraction of route (%)	Population density (km^{-2})
0–150	53.0	13.6	Rural	55	20
151–250	2.0	189.2			
251–500	5.6	358.0	Suburban	18	670
501–1200	12.6	812.3			
1201–3000	13.4	2030.1	Urban	27	3600
Greater than 3000	13.4	5240.7			
				Average:	1104 (km^{-2})

kilometre in a 1 km broad corridor on either side of the railway route results, compared with the average population density of about 248 km^{-2} in the Federal Republic of Germany.

3.2. Transport velocity

Including stops at signals, the average velocity of goods trains while under way was estimated as 50 km/h, independent of population zone.

3.3. Radiation exposure at switchyards

From information supplied by the Federal German railway authorities a stop time of 11 h per 24 hour trip was determined. Measurements of sojourn times and distances of switchmen from shipments of spent fuel casks have led to an upper estimate of 0.5 mrem collective dose[2] per switchyard and shipment.

[2] 1 rem = 10^{-2} Sv.

This value is reproduced by INTERTRAN by adjusting the input values – persons exposed while stopped – to 1.5 (switchmen) and the average stop exposure distance to 20 m in conjunction with the above stop time per 24 hour trip. One switchyard per 200 km travel distance for goods trains is assumed. It turns out that the shape factor introduced in the computer code to reflect the influence of the dimensions of the package, cask or wagon on the radiation field as a function of distance is adequate to give reasonable agreement with estimates of radiation exposures of switchyard personnel for other radioactive materials.

3.4. Exposure of people sharing the transport link

The average number of persons in a passenger train was determined as 213 from railway transport statistics. From timetables averaged over 24 h a traffic count of 2.3 passenger trains per hour passing a specific point resulted, independent of population zone.

3.5. Exposure of people surrounding the transport link while the shipment is moving

The collective dose to persons within a corridor on either side of the transport link ranging from 30 to 800 m depends among other things on population density and shielding from buildings. The default values of INTERTRAN for the shielding factor are 1 (rural), i.e. no shielding by buildings, 0.5 (suburban) and 0.05 (urban). Since the dose to people surrounding the transport link is proportional to the product of population density and shielding factor, the combined effect is a lower effective population density if the shielding factor is smaller than 1. Our analysis of shielding by the type of buildings typical for the three population zones within the Federal Republic of Germany leads to shielding factors of 0.3 (rural), 0.05 (suburban) and 0.004 (urban). But in order to take account of people outside of buildings and not to underestimate the resulting collective dose, the default values have been adopted for the analysis.

3.6. Handling of transports of radioactive materials

The only significant exposure to railway personnel is assumed to be associated with the handling of express and piece goods (receipt of the delivered packages, temporary storage, transport to platform, loading into the train, etc.). A collective dose of 0.25 mrem per handling per unit transport index is assumed by INTERTRAN for small packages. The number of handlings was set to 4 per shipment of a small package. The parameters are assumed to include the exposure of warehouse personnel.

3.7. Number of crew and mean distance to radioactive material

The computer code does not foresee an effective shielding factor between crew (engine driver, escort crew, package car personnel) and the radioactive material. Therefore, the parameter – distance from source to crew – has to be chosen appropriately to take account of the radiation field in the axial direction of large packages or wagons and of shielding by material and may not necessarily coincide with the physical distance between source and crew. A value of 2 crewmen at a distance of 15 m for railway wagons and of 7 m for baggage cars has been adopted.

4. RESULTS OBTAINED WITH INTERTRAN

The results obtained from running the computer code for all transports of radioactive materials by rail during one year (1983) with parameters as discussed above are summarized in Table III. Resulting collective doses for personnel (crewmen, handlers, switchmen) and the public (people sharing the transport link, i.e. in passenger trains and people living in a corridor on either side of the railway route) are given for each type of shipment. For different types of railway personnel the total collective radiation doses are compared with estimates of the Federal German railway authorities based on measurements of sojourn times and distances from radioactive materials [3].

As can be seen from Table III, the largest calculated dose to crewmen – in this case baggage car personnel – results from the comparatively large number of transports of piece and express goods. The agreement between the total exposure calculated for this subgroup (6.7 man·rem) and the estimate of the Federal German railway authorities (9.1 man·rem) is reasonable. This is also the case for the collective dose from handling of piece and express goods (11.1 man·rem calculated, 9.2 man·rem estimated by Federal German railway authorities). Also for switchmen the agreement within about a factor of 2 is reasonable. In total, the railway authorities estimated about 19 man·rem for their personnel from transports of radioactive materials of one year. It is interesting to have the additional information about the approximate numbers of personnel involved with transports of radioactive materials: switchmen (360), baggage car personnel (540), engine drivers (680), handling of express (970) and of piece goods (460). The average dose to personnel directly involved with the transport of radioactive materials is accordingly of the order of 6×10^{-3} man·rem.

The total collective doses to the public – surrounding population while shipments are under way and people (in passenger trains) travelling on the transport link – are 0.73 man·rem and 3.0 man·rem, respectively. The larger exposure to people in passenger trains passing the shipment in spite of the

TABLE III. RESULTS OF COLLECTIVE DOSE (MAN · REM) FROM RAILWAY TRANSPORTS IN ONE YEAR (1983) OF RADIOACTIVE MATERIALS AS CALCULATED BY INTERTRAN: COMPARISON WITH ESTIMATES AND MEASUREMENTS OF FEDERAL GERMAN RAILWAY AUTHORITIES

Type of shipment	Crewmen	Handlers	While moving Off link	While moving On link	Switchmen	Totals
UF_6	3.1.E-2		8.6.E-3	3.5.E-2	6.0.E-3	8.1.E-2
UO_2 or U_3O_8 powder	6.5.E-3		1.8.E-3	7.4.E-3	1.2.E-3	1.7.E-2
Fresh fuel elements	4.6.E-2		1.3.E-2	5.2.E-2	8.8.E-3	1.2.E-1
Spent fuel elements	5.6.E-1		1.6.E-1	6.4.E-1	1.1.E-1	1.5.E+0
Radiation sources	1.3.E-2		3.7.E-3	9.5.E-2	2.6.E-3	3.4-E-2
Uranium ore/concentrates	4.5.E-1		1.3.E-1	5.1.E-1	8.7.E-2	1.2.E+0
UF_6 (depleted)	2.9.E-2		8.1.E-3	3.3.E-2	5.6.E-3	7.6.E-2
Low level waste	2.2.E-2		6.1.E-3	2.2.E-1	4.2.E-3	5.7.E-2
Piece goods	8.4.E-1	1.5.E+0	5.1.E-2	2.1.E-1	3.5.E-2	1.1.E+0
Goods shipped by express	4.7.E+0	9.6.E+0	2.8.E-1	1.2.E+0	2.0.E-1	6.4.E+0
Totals:	6.7.E+0	1.1.E+1	7.3.E-1	3.0.E+0	4.5.E-1	2.1.E+1
Estimates + measurements of railway authorities	9.1.E+0[a]	9.2.E+0[b]			1.1.E+0	1.9.E+1[c]

[a] This number combines 3.7 man·rem (engine drivers) and 5.4 man·rem (baggage car personnel).
[b] This number includes only exposures from handling of piece and express goods.
[c] This number includes only exposure of railway personnel.

smaller number results from the much shorter exposure distance. It is evident that individual doses are so small that it is doubtful from the radiological point of view whether they have any significance with respect to the associated health risk. In any case the calculated collective dose to the public is about a factor of 5 smaller than the dose to railway personnel.

5. CONCLUSIONS

For incident-free transports of radioactive materials, the models for calculating resulting collective doses for different population subgroups are rather straightforward. The modelling as used in INTERTRAN is able to produce reasonable results. It is the quality of the parameters supplied by the user which essentially determines the quality of the results. It is felt that results presented for all transports of radioactive materials by rail in one year are a reasonable estimate of associated collective doses. In the case of different groups of railway personnel this is supported by the agreement with estimates of collective doses derived by the Federal German railway authorities and based on sample measurements of dose rates, sojourn times and distances of personnel close to radioactive materials. Efforts are presently under way to collect data relevant to the estimation of risks associated with transports involving accidents with the aid of INTERTRAN. The results presented here for incident-free transports should form a reasonable basis for the comparison of the relative risks from normal case transports and transport accidents with radioactive materials.

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