SEGREGATION OF PACKAGES DURING TRANSPORT

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INTRODUCTION

The IAEA transport regulations [IAEA SS6 1990] require radioactive materials to be segregated sufficiently from workers, members of the public and photographic film. Specific values of annual effective dose for workers and members of the public are given for the purpose of calculating segregation distances or radiation levels. Segregation distances for film are based on a maximum exposure per consignment. The mathematical models, parameters and values to be used in calculating segregation distances are no longer in the regulations but are in various other reports and these have been examined and reviewed for their consistency with current radiation dosimetry and operational procedures.

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REVIEW OF MODELS AND DATABASES

Calculation of segregation distances[IAEA SS 37 1985] for packaged radioactive material was, and still is, basically related to three fundamental quantities for all modes of transport and storage in transit situations. These are (a) the package dose rate distribution in regularly occupied areas, either of a conveyance, or in a storage area; (b) the exposure time of persons or photographic film travelling with or stored in proximity to radioactive material packages; and (c) the radiation dose considered to provide an appropriate level of protection for people and materials. It is evident that the first two of these key quantities can vary considerably, depending on the mode and conditions of transport.

Over the past 35 years, simplification has been introduced into the modelling process with the objective of facilitating development of criteria for segregating radioactive materials in a conservative manner.

A major point of conservatism inherent in estimating segregation distances is that the limiting values of dose are applied at the boundary of a regularly occupied area, whereas most persons will be moving around beyond the limiting boundary edge. Another simplification in calculating segregation distance is to treat a package or an assembly of packages as a point source of radiation with the source considered to be located at the centre. The maximum radiation level at 1 m from the package surface has been defined as the transport index (TI). The radiation level at various distances from the package surface is calculated using the "single point source-inverse-square" relationship. This method was employed during movements of the earliest sources of radioactive material, the radiotherapy radium-226 sources, although few transport movements currently match that original criterion.

If a radioactive material of fixed strength were subdivided into several packages for transport, then, for the array of packages, summing the individual transport index values is one procedure for estimating consignment transport index. As can be seen from the estimates made for Table 1, measurements at 1 m separation from extended arrays of these packages can lead to under-estimation of the calculated radiation level at various distances.

Self-shielding within an array is an important factor. Measurements on a large array of ~150 radionuclide packages, showed a 40% reduction in estimated radiation levels arising from self-shielding. For radioactive sources of large physical dimensions, radiation levels will decrease less rapidly with distance, particularly at distances which are not much greater than the source dimensions. Only at a large distance will an 'inverse-square' relationship be achieved.

For high density, bulk radioactive material or surface-contaminated objects, point source geometry is modified by the use of additional factors. The situation and potential for over-estimation is illustrated by comparing theoretical dose rate distributions from a single 200 litre drum with that from a very large 4 x 30 array of stacked 200 litre drums, each drum having a normalised dose rate of 0.02 $mSv.h^{-1}$ at 0.1 m from the drum surface. The corresponding TI value for a single drum can be taken as being approximately 0.21. For the 4 x 30 array of stacked 200 litre drums, which can be considered as a very large area radiation source of some 60 m^2, using a multiplication factor of 10 gives a TI value of 2.1. The alternative procedure adopted by the Transport Regulations, however, would suggest a summed consignment TI-value of 0.21 for each of the 120 drums, giving a total of 25.2. When this is compared to the estimated TI-value of 2.1, an over-estimation by a factor of 12 would arise. Figure 1 incorporates these calculated dose rates for 1 and 120 drums of uranium ore concentrate (UOC) and compares the values with measured dose rates obtained from actual consignments. The larger-area source dimensions in the example above are equivalent to the typical transoceanic shipment dimensions of uranium ore concentrate, for which these results are useful in developing an understanding of the potential of over-estimation by using the sum of TI-values for determining minimum segregation distances.

TRANSPORT OPERATIONS AND THE EXPOSURE MODEL

The exposure times of persons and photographic film are fundamental in determining the required separation for each transport mode. The following variables, dependent on travel time, cargo frequency and work requirements, were used to provide the initial parameters for assessing exposure:

maximum annual travel period [**MATP**], for:- crew and passengers at risk;
radioactive traffic factor [**RTF**], the ratio of annual number of journeys spent carrying radioactive material, compared to the annual total of all journeys;
maximum annual exposure period [**MAET**] amounts to [**MATP**] x [**RTF**], for both crew and passengers.

For workers in three of the four modes of transport, exposure time was related to a 40 h week, for 50 weeks in a year, whilst, for the fourth mode, it was realised that seamen could spend considerably greater periods of time at sea, than 2000 duty hours because of the method of duty-rostering employed. An additional several thousand hours were known to be spent on-board some vessels, hence MATP was set at 8,000 hours[(Aspinal et al,1963)]

ROAD TRANSPORT Road transport in the UK involves materials in two categories:- packages too heavy for manual handling (irradiated and non-irradiated nuclear fuel-cycle materials) and packages suitable for manual handling (radionuclides). In both cases, consignments occur with about the same frequency, but, for the first category, all have remote handling of packages, and ~2 m separation between drivers' seat and load, whilst for the second category, requirements on an almost daily basis to nuclear medicine departments, give rise to daily exports to mainland Europe and the rest of the world. It is not possible to completely segregate transport drivers from these latter consignments of multiple small packages and, as a consequence, their exposure is the highest of all transport workers, largely as a result of manual handling of packages with significant surface and near-field dose rates.

RAIL TRANSPORT Rail transport in the UK is broadly limited to power stations, which, once a week on average, consign a pair of flasks containing spent nuclear fuel, to the re-processing site, a few hundred kilometres distant. Crew of such trains no longer undertake the complete journey, but, instead, stop at a regional boundary where the train and crew change with staff and equipment from the adjoining region. Thus, crew are unlikely to be undertaking 2000 h of duty, transporting radioactive material, but instead, are more likely to be making a single 4 h journey, once a week, with loaded flasks,for 50 weeks in a year, for only 200 h. y^{-1} of potential exposure time.

SEA TRANSPORT Ships' crew were generally on duty for a 2000 h period like other transport workers, but they were on board for much longer periods. Conservatively, an 8000 h maximum annual travel period (MATP) was assigned. A recent UK study shows seamen still undertaking voyages requiring 6000 h of time spent at sea during the year, although the average is closer to 4000 h.y^{-1}. For the maximum annual travel period, radioactive material is carried on three out of four oceanic crossings. However, the 300 m long vessels utilised are amongst the largest in transoceanic service with space made available greatly in excess of the required separation:- 150 to 200 m separation where only 20 to 30 m is stipulated in the segregation tables.

AIR TRANSPORT For air transport, extensive rest periods are required for flight crew. Flights carrying radioactive materials are outward bound from the UK with very few packages carried on return flights. Germany has a substantial nuclear power based program and non-irradiated nuclear materials production facility, but no major radionuclide production factory, although application of radionuclides in nuclear medicine is much higher in the UK. Radionuclides are therefore imported from other states. Although preliminary, the information available regarding transport operations shows that the RTF factor for air transport (1 in 24 flights) in Germany, differs from the values suggested by the IAEA advisory material and is about a third of the UK value (1 in 8 flights).

REVIEWS Within the UK, periodic reviews of transport have been carried out over the past 15 years: these have shown substantially shorter times of exposure than had been originally supposed. Over the same period, changes in operational factors in all four transport modes have occurred, further reducing the exposure of transport workers.

SEGREGATION DATA

Investigations have been made in the UK[Gelder,1990,92, 96, & 97] on consignments of radioactive material whilst being transported by road, rail, air and sea. Table 2 illustrates where segregation has been applied.

RADIONUCLIDES Radionuclide packages, for medical use, are regularly despatched by road transport around the UK. Packages are small and are carried in large numbers, up to several 100 at the start of routing, reducing to less than 10 per vehicle, as distributions around the country are completed. Vehicles used are 3 to 5 m long, for consignment TIs of 50 to 200 at start, reducing to <5 TI at final delivery. Currently, radionuclide packages are unlikely to be carried by rail within the UK or Germany. Radionuclide packages are routinely transported by air, most on passenger flights with bulk consignments on freighter aircraft. There are two main types of passenger jets and separation spacing is restricted to 1 m (narrow-bodied jets) or 1.8 m (wide-bodied jets) : segregation limits are met by limiting the TI carried in any one aircraft hold[ICAO,1997]. Examinations of flight records in the UK showed that activity limits were strictly observed; that on average the TI carried was considerably less than the maximum permitted; over-lying baggage and other goods contributed significantly to reducing dose rates in occupied cabin areas, and annual times of exposure were much less than originally estimated. The regular rotation of cabin staff duties limits doses arising from these transport movements to less than 0.5 mSv. y^{-1}. Passenger flight frequency also restricted exposure, even for the frequent flier, to less than 0.1 mSv. y^{-1}. An exception to this flight pattern arose for a specialist group, the couriers on short-haul flights into Europe, acting as escorts for urgently required goods and using the same flight pattern as that for some consignments of radionuclides. Individual exposure of couriers was estimated as some 0.4 mSv. y^{-1}. Not long after assessing this group of passengers, the despatcher utilised a freight aircraft on this particular route. This does not preclude similar patterns existing on other European routes. Sea transport of radionuclides consisted of either individual packages (radiotherapy or industrial radiography sources) carried on voyages longer than a week; or multiple consignments carried on short one hour duration voyages, cross-Channel. In this latter case, the intervening decking and other cargo reduced exposure rates in regularly occupied areas for passengers and crew. A close examination of MAET showed that the exposure period was a few tens of hours in a year. This movement ceased in mid-1996 and the transport operation transferred to the Channel Tunnel and freight train.

RADIONUCLIDE PACKAGE HANDLING Road transport drivers are involved in considerable manual handling during loading and off-loading, which accounts for an estimated 80% of dose received by these workers. Where limited duration stops are necessary during transport movements, areas have been set aside for these vehicles at road, rail, sea and air depots, and at hospital premises. Most of the 200 road drivers, registered as designated workers, wear personal dose meters, but in 1996, less than 20 of them received a dose exceeding 5 mSv. Although other modal transport workers are involved in limited manual handling of radionuclide packages, none achieve an annual exposure exceeding 1 mSv. Only transient exposure of members of the public occurs during such operations; individual exposures are estimated as less than 0.1 mSv.y^{-1}.

IRRADIATED NUCLEAR FUEL CYCLE MATERIALS In the UK, some thirteen power stations routinely despatch an annual total of about 600 flasks of spent nuclear fuel by road on short journeys, from power station to rail link. These movements are limited to distances of a few kilometres and are of duration for less than one hour, twice a week. The subsequent rail movements involve longer journeys of up to 48 h. Except at railheads where loading / unloading takes place, segregation from workers in railway marshalling yards is ensured by the use of rail lines furthest from regularly occupied working areas. Likewise, members of the public are located at separation distances at or exceeding 100 m, the boundary separation distance when flasks of spent nuclear fuel are halted in marshalling yards. Whilst separation of housing from rail lines is variable, exposure, at or in houses during movements of flasks, is transient and, on average, is less than one hour in a year. Imported spent nuclear fuel is received about 12 times a year at a dedicated sea terminal where it is transferred to rail for about a 1 h journey, under similar conditions to the other UK flask movements. Road transport worker exposure is limited to some 2 mSv a year, largely from other duties on the power stations, rather than from transport duties, including flask transfer at rail heads. Exposure during flask transfer at the sea terminal is approaching a similar value of exposure. Individual public exposure has been estimated as less than 0.01 mSv in a year. Exposure arising from imported flasks during either the two day voyages from Europe or the six to twelve week voyages from Japan is largely due to essential daily inspections of flasks in below-deck holds, for selected crew working in close proximity to flask surfaces. Doses recorded during voyages have been at the limit of detection of the dosemeters employed and annual doses are less than 1 mSv.

NON-IRRADIATED NUCLEAR FUEL CYCLE MATERIALS More than 10,000 tonnes of low specific activity (LSA) materials are transported in a year within, to and from the UK, with a similar quantity in transit through UK ports. Most movements consist of imports of uranium ore concentrate and transfers or exports of uranium hexafluoride. Movements by road are normally of some few hours duration, for distances of 100 to 300 km to power stations, to ports and between two producer factories. Segregation on vehicles is some 2 m between load and driver and between 3 and 30 m for members of the public during these road transport operations. Rail transport of these LSA materials is occasional, with the majority being transported by a dedicated road vehicle fleet belonging to the principal UK processor of these LSA materials. In 1996, some 500 sea transport movements of uranium ore concentrate and uranium hexafluoride took place in the UK. Segregation on regular freight movements was strictly observed and on the most frequently used vessels [trans-Atlantic] separation was further increased by an additional factor of ten [20 m to 200 m] for the typical average cargo of five containers of material shipped. In all situations where space was available, separations at and greater than the required segregation distances were found to apply. Intervening cargo substantially reduced exposure rates in regularly occupied areas. Estimated annual doses were well below values of 1 mSv and most at levels less than 100 μSv, this latter contribution arising during docking, loading and discharge of cargo, when crew presence was required within the segregation area containing the cargo.

SEGREGATION BY DOSE RATE CONTROL
In the IMDG Code[IMO,1994], an alternative is proposed, to using segregation obtained from predetermined distances. In the section dealing with Segregation Requirements [page 7019, para 4.5.6].

"The appropriate segregation may be established by .....,for exposure times up to 700 hours in a year, the direct measurement of the radiation level at regularly occupied spaces .....is less than 0.0075 $mSv.h^{-1}$.....If the exposure time....is likely to exceed 700 hours in a year, then the measured radiation level at regularly occupied spaces.....should be less than 0.0018 $mSv.h^{-1}$. In all cases the measurements of the radiation level must be made and documented by a suitably qualified person."

This methodology could lead to higher annual doses than the segregation distance method for similar annual times of exposure. In the segregation methodology, the space between the cargo of radioactive material and the regularly occupied space is occupied by other intervening cargo. These other cargo materials provide considerable additional shielding.

EXPOSURE LEVELS IN THE UK
The most significant road transport operations, when transport workers occupy areas where annual doses can exceed 5 mSv, are those where handling of multiple radionuclide packages occur. Some ten years ago, annual doses for the 12 most exposed persons in this group of workers ranged from 5 to 15 mSv. With improved operational controls and additional remote handling equipment, the annual dose range has reduced to 2 to 8 mSv, with further reductions possible as other practices and additional remote handling equipment are used. For rail transport, the significant operations consist of flask transfers and their dwell times of a few hours in marshalling yards. Annual doses to transport workers are 0.1 mSv on average, and members of the public at marshalling yard boundaries receive less than 0.01 $mSv.y^{-1}$. Annual doses to crew on aircraft and to handlers at airports are less than 1 mSv, due to consignments on average not exceeding 10% of the maximum allowed TI per flight and to duties shared amongst all staff, reducing substantially their annual times of exposure. At sea, for more than a thousand shipments (98% of voyages) into or from the UK, annual doses to crew were less

than 0.1 mSv and for passengers, less than 0.03 mSv. On the remaining 2% of voyages, annual doses were assessed as up to 1 mSv for crew and less than 0.1 mSv for passengers. Estimated annual doses to transport workers are shown in Table 3.

DISCUSSION

The objective of radiation protection in the transport of radioactive material is to provide an acceptable level of protection of people, environment, and property against the potentially adverse effects of ionizing radiation. In normal transport of radioactive materials, segregation plays an important role in the existing Regulations to ensure a suitable level of protection. It is however important to recognize that a safe level of protection may be achieved in various ways, for example by providing shielding of regularly occupied areas or by adjusting working schedules. Moreover, the existing regulatory framework provides several independent levels of control for personnel to limit the radiation exposure of individuals, for example, the implementation of radiation assessment and monitoring programmes in addition to the mandatory segregation requirements.

Periodic assessments of radiation doses to persons due to the transport of radioactive material, undertaken on behalf of the competent authority in the UK[Gelder, 90,92,96 & 97], show that, where control has been by segregation distance, then no person has exceeded the values of dose, used for caculating segregation distances, that is, 5 mSv for workers and 1 mSv for the critical group of members of the public. An evaluation has been made of frequency of transport movements; the TI values of cargoes carried; the dose rates arising in the regularly occupied areas; the rostering practices of workers involved in these movements; and resulting times of exposure. Instances arise where considerably reduced values of maximum annual exposure time (MAET) are linked to specific aspects of the transport mode investigated. For example, cross-Channel ferries operate with very short voyage times; within fleet groups, aircraft cabin crew may be randomly selected from a much large work group for flights on which radioactive materials are regularly carried. Estimates of effective time of exposure demonstrate the changes from values determined 35 years ago, when the Regulations were first initiated, to present times, where modern practices have had a profound effect in changing actual times of exposure. Segregation tables show distances as a function of total TI. The TI values are determined in several ways, one of which requires the application of multiplying factors: these factors have changed since the early publications and are currently being reviewed. In addition, for many assessments, the TI (the maximum dose rate) was directed towards transiently occupied areas only, with lower dose rates directed towards regularly occupied areas.

RADIATION DAMAGE TO PHOTOGRAPHIC FILM

No reports have been received of radiation damage to film stocks due to transport of radioactive materials in adjacent areas on trans-Atlantic sea-routes, which is where the bulk of such movements occur in the northern hemisphere.

CONCLUSIONS AND RECOMMENDATIONS

The current segregation systems were developed several decades ago and their full justification and explanatory material is now difficult to obtain. Values and parameters used are significantly out of date but the inherently conservative system still results in adequate protection of persons and goods. However the segregation distances and dose rates derived from the models are in some cases likely to be unnecessarily restrictive.

It is recommended that:

- there be a consistent approach in the future for all modes of transport,
- updated systems be more realistic and avoid being unnecessarily restrictive,
- models, values and parameters be available in a single publication.

Care should be exercised when determining parameters for international use. Some of the original factors related to the modes of transport have been found to be better described by a range of values, rather than by a single figure.
The current system still contains a high level of conservatism.

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Table 1 TI values arising from the geometrical re-arrangements of a common source.

Source TI value	Package Geometry	Source size (not package size)	Dose rate at 1 m, $\mu Sv. h^{-1}$	Consignment TI value
TI = 18	Point source	Point	133	13.3
9 x (TI = 2)	Square Array	0.66 m x 0.66 m	120	12
9 x (TI = 2)	Line Array	2.67 m long	94	9.4
18 x (TI = 1)	2 Square Arrays	0.66 m x 0.66 m twice, 0.66 m apart	86	8.6

At 10 m from the four different source arrays, dose rates agree with each other to within 6%.

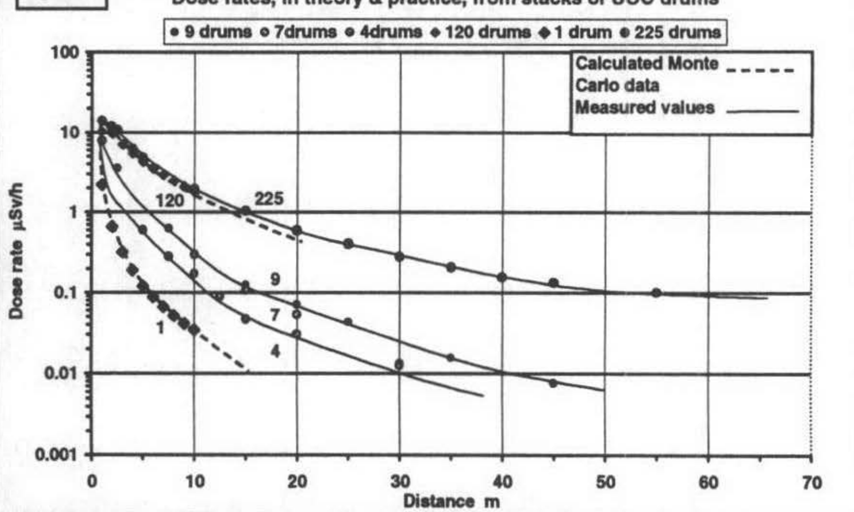
Table 2 Application of Segregation in UK Transport

Transport Mode / Materials	Road	Rail	Air	Sea
Radionuclides	No	Not applicable	Yes	Long voyages =Yes Short voyages = No
Irradiated fuel-cycle materials	Yes	Yes	Not applicable	No.
Non-irradiated nuclear fuel-cycle materials	Yes	Yes	Not applicable	Yes

Table 3 Annual Doses received by transport workers when control is by distance (Segregated) or otherwise (Not Segregated)

Estimated Annual Doses [Segregated]				
	Road	Rail	Air	Sea
Radionuclide packages	Not applicable	Not applicable	< 0.5 mSv	Range 0.1 to 1 mSv
Irradiated nuclear fuel-cycle materials	2 mSv	< 1 mSv	Not applicable	Not applicable
Non-irradiated nuclear fuel-cycle materials	1 to 2 mSv	<1 mSv	Not applicable	< 0.1 mSv (average)
Annual Doses [Non-segregated]				
	Road	Rail	Air	Sea
Radionuclide packages	Range 5 – 8 mSv	Not applicable	Not applicable	Not known
Irradiated nuclear fuel-cycle materials	Not applicable	2 mSv	Not applicable	< 1 mSv (crew) <2 mSv (dockers)
Non-irradiated nuclear fuel-cycle materials	Not applicable	<0.1 mSv	Not applicable	0.6 mSv [UOC] <1.2 mSv [HEX]

Figure 1 Dose rates, in theory & practice, from stacks of UOC drums



SESSION 14.2

Transport of MTR Spent Fuel