World Nuclear Transport Institute

INFORMATION PAPER

Radiation Dose Assessment for the Transport of Nuclear Fuel Cycle Materials

Dedicated to the safe, efficient and reliable transport of radioactive materials

Radiation Dose Assessment for the Transport of Nuclear Fuel Cycle Materials

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Summary

The nuclear power industry, which supplies some 16% of the world's electricity, is becoming increasingly global in terms of both products and services. The national and international transport of nuclear fuel cycle materials by all modes of transport is essential to support this activity.

The IAEA Transport Regulations require transport organisations to implement Radiation Protection Programmes (Annex 1) to control radiation dose exposure to workers and the public. Dose assessment is a key feature and the exposure which workers are likely to receive determines the degree of dose monitoring which is required. For transport operations where the expected dose is below 1 mSv/year no dose monitoring of workers, members of the public or the workplace is required.

This study makes an assessment of the likely doses to various types of worker in nuclear fuel cycle transport operations and also to members of the public based mainly on the extensive experience of actual operations. It covers all the main nuclear fuel cycle materials from uranium ore concentrates through to spent fuel. All the main modes of transport, i.e. road, rail and sea are also covered.

The conclusion is that it is very unlikely any group of workers not classified as radiation workers, or any member of the public, will receive annual doses in excess of 1 mSv [i], i.e. all the transport operations for nuclear fuel cycle materials should fall below the dose level for which workplace or individual dose monitoring is required.

(i) The biological effects of radiation on the organism exposed are measured in Sieverts (Sv). This is a health physics unit. It is expressed in dose equivalent and takes into account the characteristics of the radiation and of the organ irradiated. The millisievert (mSv) or one thousandth of a sievert and the microsievert (μSv) or one millionth of a sievert are often used. Throughout the world, the annual average dose equivalent due to natural exposure is around 2.4 mSv.

Background

Many thousands of radioactive material packages are routinely transported annually both within and between countries by road, rail, sea and air. In Europe alone there are over 1 million shipments a year. The materials vary widely and include small quantities of radio-pharmaceuticals for medical use, highly radioactive sources for use in medical diagnosis and therapy, sources for use in industry and research as well as the full range of nuclear fuel cycle materials, including uranium concentrates, fresh fuel through to spent fuel and radioactive wastes. The vast majority of the shipments of radioactive materials are radio-pharmaceuticals for use in medicine or radioactive isotopes for industrial use. Nuclear fuel cycle materials comprise only a small fraction in terms of shipment numbers but they represent a significant proportion of the total radioactivity transported.

The radiation protection regime

In order to control radiation dose exposure to workers and the public from transport operations, the IAEA Transport Regulations, TS-R-1 [(1)], now require the organisations involved to implement a Radiation Protection Programme (RPP). It is necessary to ensure that these programmes are implemented properly to protect the public and those workers who are involved in loading and unloading operations, storage in-transit and shipment of radioactive materials, who are not classified as radiation workers.

In some cases nuclear fuel cycle materials are transported by dedicated carriers, such as for the transport of spent fuel and high-level waste between Japan and Europe. However, there are many transport organisations for which the transport of nuclear fuel cycle materials and sources for medical and industrial use is only a small part of their business. Typical of these are trucking companies, sea carriers, port handling organisations and airline services, which involve workers who are not classified as radiation workers, as well as members of the public, where the Regulations call for an RPP to be established.

The radiological protection requirements for the handling and movement of radioactive materials within a nuclear establishment, e.g. a fuel plant, a nuclear power plant or a reprocessing facility, are covered under the nuclear site licence and the IAEA Transport Regulations do not apply.

The graded approach based on dose assessment

RPPs are intended to provide and document the framework of controls applied by a transport organisation to limit the normal and potential exposure of workers and the public. The nature and extent of control measures in the RPP should relate to the magnitude and likelihood of radiation exposure; i.e. a graded approach.

RPPs have to include details on the procedures to be adopted to achieve optimisation of protection and safety including such issues as dose assessment, segregation of packages, emergency response, training and quality assurance. Of these dose assessment and evaluation are key issues for RPPs and this includes both a dose assessment at the pre-operational stage to ensure that account has been taken of all reasonably practicable radiation protection measures and radiation monitoring and dose assessment where appropriate during transport to demonstrate compliance and establish good practice.

The level of expected dose exposure forms the basis for a graded approach to the requirements of the RPP, in particular the degree of dose monitoring which is required where it is expected that the effective dose:

(a) is likely to be between 1 and 6 mSv in a year, a dose assessment programme via workplace monitoring or individual monitoring shall be conducted;
(b) is likely to exceed 6 mSv in a year, individual monitoring shall be conducted.

When individual monitoring or workplace monitoring is conducted appropriate records have to be kept.

The 1mSv/year effective dose is the International Commission on Radiation Protection dose limit for members of the public and therefore the requirements for an RPP are considerably below this level.

The Regulations accept that the likely dose will generally be based on a prior radiological assessment using existing dose data for similar transport activities. This is the reason why it is important to collect reliable dose data relating to transport operations for nuclear fuel cycle materials.

Objectives of this study

This study makes an assessment of the likely doses to various types of worker in the transport chain and also to members of the public for the transport of various fuel cycle materials, based mainly on experience of actual operations, with the objective of establishing the basis on which appropriate RPPs can be prepared.

The study considers the various types of worker in the transport chain and also the public, the main modes of transport and the main radioactive materials, as follows:

- workers – loading and unloading workers, crew/drivers, inspectors, supervisors;
- mode - rail, road, sea;
- materials - uranium ore concentrate (UOC), uranium hexafluoride (Hex), oxide powder, new fuel, spent fuel, plutonium, mixed oxide fuel (MOX) and wastes.

Dose assessments methods

The radiation doses received by workers and the public during radioactive transport operations depend on such factors as:

- package dose rate;
- time of exposure;
- segregation distance;
- shielding arrangements.

Taking account of these factors there are several methods of assessing the likely dose uptake based on:

- computer codes;
- estimates using assumed scenarios and dose rates from packages;
- estimates based on the Transport Index;
- data from direct measurements.

There are several published studies using all these methods and covering the major nuclear fuel cycle materials. However the studies are fragmented and, in some cases, specific to particular situations. They require careful analysis to establish confidence in their accuracy and validity. Data from direct measurements or estimates based on assumed transport scenarios and dose rates from packages are the most reliable. Computer codes can also give a useful guide but estimates based on the Transport Index lead to overestimates as they are derived from the highest dose rates from the surface of the packages. For accurate assessments, the dose rates should be those in occupied areas combined with appropriate exposure times.

The aim in this paper is to use the best data, which represent current practice from both existing published sources and records of WNTI member companies.

Dose up-take of transport workers

Road, rail and sea transport are all commonly used for nuclear fuel cycle materials. Air transport is performed to a very limited extent.

For road transport, non-irradiated nuclear fuel cycle materials, i.e. uranium ore concentrates (UOC), uranium oxide powder and Hex, are normally carried in containers on trailers with drivers' cabs separated by 1-2 m. Loading is by crane or lift-truck with limited access by workers. Similar conditions apply to rail transport. The quantities of UOC and Hex are quite large; e.g. in the UK some 6000 te per year of UOC are handled, about 1000 te for use in the UK and 5000 te for export after processing, mainly to Hex. Of the 2000 or so annual movements per year about two-thirds travel by road and one-third by rail. The situation will be similar in other countries with a fuel cycle industry.

Spent nuclear fuel is transported within Europe mainly by rail with road transport confined to the short journeys from reactor site to the railhead. Spent fuel is transported from Japan to Europe for reprocessing by sea in dedicated vessels to sea terminals close to the reprocessing plants followed by short road/rail journeys. For spent fuel, crane handling of flasks is employed with limited access by workers. Some spent fuel is likewise transported from Europe to the UK. The limited transports of high-level waste, for example from la Hague in France to storage facilities in Germany or from Europe to Japan, are closely similar to spent fuel transport. MOX and plutonium transports are also similar.

Low and intermediate-level wastes are transported by road under conditions similar to those for UOC that is packed in drums and loaded into ISO containers. Rail transport is similar.

The individual dose up-takes to workers and the public resulting from the transport of the various nuclear fuel cycle materials by different modes of transport are discussed below.

Road transport

Non-irradiated fuel cycle materials (UOC, Hex, oxide powder and new fuel)

Reliable data from measurements are available for the road transport of non-irradiated fuel cycle materials in the UK [(2)] covering some 1600 movements involving 26 drivers employed as radiation workers who would carry out other duties on nuclear sites and 50 contract drivers who would collect and deliver consignments only. The individual dose was estimated to be 100 μSv per year for drivers carrying out 20 - 40 journeys per year.

Other data [(3)] from Germany for Hex and new fuel transport showed typical dose rates at 1m from the load of about 3 μSv per hour. Assuming an occupancy of less than about 100 hours per year would give a dose of about 300 μSv per year for the loaders. The dose rate for drivers was generally less about 0.5 μSv per hour giving an annual rate of about 200 μSv for 400 hours per year (2 hours per day).

These estimates are backed up by direct dose measurements [(4)] on truck drivers carried out by Nuclear Cargo & Service GmbH which showed annual dose rates of 200 – 300 μSv for 8 drivers over the years 1990 – 1999 for a variety of materials including new fuel assemblies, Hex, low-level waste, MOX fuel and irradiated samples in lead casks.

Direct measurements over several years on contract drivers in the UK for BNFL delivering front end non-irradiated materials showed a maximum of 670 μSv per year with an average of 430 μSv per year [(5)].

Japanese data [(6)] for new fuel transport by road showed that for both handlers and drivers the dose uptake for work outside the site only was below the limit of the monitoring film (100 μSv per month). Taking into account work in the operating area as well as outside the site, the average dose in 1997 and 1998 was about 100 μSv per year with a maximum of 300.

Public exposure from road transport occurs as the result of the overtaking of vehicles carrying radioactive materials. In the worst case the dose is unlikely to exceed 4 μSv per year [(2)].

Spent fuel

Dose up-take data are available [(3)] for the road transport of spent fuel carried out in the UK. Dose records for five drivers who transported to the railhead 35% of the 471 Magnox flasks handled in one year showed a maximum individual dose of 500 µSv and an average of 370 µSv. Drivers who transported AGR fuel carried out fewer journeys and did not exceed 50 µSv in a year. Drivers delivering flasks entirely by road received 220 µSv as the maximum annual dose for transport.

Data from Japan [6] for spent fuel transport by road showed that for both handlers and drivers the dose uptake for work outside the site only was about 2 µSv per year with a maximum of 9. Taking into account work in the operating area also the average dose was 500 – 700 µSv per year for operators and 250 µSv per year for drivers. The maximum value for operators was 8100 µSv per year but this would be for a classified radiation worker with a range of duties and it is likely that not more than 10% of the dose would be due to transport operations. For drivers, the maximum was 500 µSv per year. For other transports, e.g. combinations of materials, maximum doses for work outside the site were about 100 µSv per year and including work in the operating area about 500 µSv per year.

Low-Level and Intermediate-Level Wastes (LLW/ILW)

Data for the UK [2] were obtained for 58 transport workers at the Sellafield reprocessing site and the associated LLW disposal site at Drigg some 15 km away. Disposal site duties required eight out of the 58 to work there on rotation. Annual doses ranged from 400 to 4000 µSv. Likewise six drivers from the UK enrichment plant received maximum annual doses of 630 µSv with an average of 260 and nine drivers from a Magnox power station who carried out 41 ILW movements and 63 spent fuel movements entirely by road received annual doses ranging from 600 to 1600 µSv. For all three groups, other site duties accounted for at least 90% of these doses so that the doses attributable to transport are only 10%, i.e. from about 26 to 400 µSv per year.

Summary of Maximum Dose Uptake for Road Transport (µSv per year)

Persons	Non-irradiated	Spent fuel	Wastes (LLW/ILW)
Handlers	300	<1000	
Crew	100-700	200-500	20-400
Public	<4	<4	<4

Rail Transport

Non-irradiated fuel cycle materials

Measurements were carried out by the Institut de Protection et de Surete Nucleaire and the Office de Protection et de Surete Nucleaire (IPSN/OPRI) in France [7] in January 1999 to assess the radiation doses to railway workers for UOC transport. The consignment was a trainload of 0.5% U_3O_8 from Pierrelatte destined for the storage facility at Bessines and consisted of 10 wagons each containing 6-7 type DV70 containers ('green cubes') which can hold 6-12 tonnes each. Fifty trainloads per year were envisaged. The doses were evaluated for the various operatives. The most exposed person was the train assembler at Pierrelatte with a dose of 6 µSv. For the maximum of 50 trainloads per year the highest dose would be 300 µSv per year, that is well below the limit of 1000 µSv. The dose to the train driver was not much greater than the natural background.

A similar programme of measurements was carried out in France by IPSN/OPRI in April 1999 [8] on a trainload of 3.5% enriched Hex from Pierrelatte destined for Anvers en route to the USA. The consignment consisted of a total of 38 cylinders of Type 30B. Measurements were taken of radiation levels along the train and also in contact with the cylinders. The results showed that the dose rates were very low, generally about 1-2 µSv per hour with the maximum values of about 6. It was concluded that the radiation doses received by the railway workers under normal conditions were well below the 1000 µSv per year limit. In fact by comparison with the transport of U_3O_8, since the dose rates for Hex are less than half and the number of shipments also likely to be less than half, the maximum dose would be less than one quarter, i.e. less than about 75 µSv per year.

Spent nuclear fuel

Measurements were carried out by IPSN/OPRI in September 1999 [9] to assess the dose uptake to railway workers handling wagons loaded with spent fuel at Valognes en route to la Hague. Doses were estimated for the various operations based on assumed durations and measured dose rates. The results showed that doses varied from 1.8 to 4.1 µSv which indicates that some 550 operations representing 140 hours of work or 250 consignments representing 500 hours of journey time would be needed to reach the dose limit of 1000 µSv per year. These are far higher than railway workers would experience in the course of their normal work and the dose rates would therefore be substantially less than the limit.

In the UK in 1989, 635 flasks of spent fuel were transported from UK nuclear power stations, 16 flasks from mainland Europe entering at a southern port and 104 flasks from Japan entering at Barrow were transported to Sellafield by rail. Data for this rail transport [2] showed that a few handlers at busy railheads received annual doses of 140 μSv. The average dose was 40 μSv per year. Four inspectors received 75 μSv. Most other workers such as drivers, guards and shunters do not generally exceed 2 μSv per year.

Another study [10] on the dose assessment for spent fuel transport was carried out using Intertran2, a computer programme developed by IAEA for the calculation of collective and individual doses to workers and the public. Assuming the transport of 200 packages per year this showed that the maximum annual dose to the train crew would be about 800 μSv, to the handler at Valognes about 4000 μSv. These estimated doses are much higher than those from direct measurements.

OPRI in France has concluded that doses to railway workers are less than 1000 μSv per year and they do not need to be classified but they should receive appropriate training.

For spent fuel movements by road or rail the most exposed individuals in 1989 were flatroll maintenance workers stationed permanently at the reprocessing site at Sellafield who recorded 1800 and 2300 μSv but whose doses halved the following year [2]. These doses do not arise directly from their maintenance work but also from other radiation sources.

The most exposed member of the public from rail transport is postulated to be a householder living on the boundary of a marshalling yard 100m from where spent fuel is being held. The maximum dose was estimated [2] to be 6 μSv per annum. For persons living 50m from a railway line the dose would be very much less.

High-level waste (HLW)

A theoretical study [11] has been carried out using Intertran2 on the transport of HLW together with some LLW bituminised waste shipments resulting from the reprocessing of German spent fuel at la Hague. The transport would be mainly by rail and road transport would be limited to the short journeys between la Hague and Valognes and Dannenberg and the storage facility at Gorleben. The dose rates at 1m from Castor HLW casks is about 100 μSv/hour, for TN28 flasks it is 40 μSv/hour and for bituminised waste containers 200 μSv/hour. Assuming 15 HLW shipments and 50 bituminised waste shipments per year the doses at Valognes were estimated to be between 1700 and 700 μSv per year for the various handling operations, the train crews between 100 and 200 and the handler at Dannenberg 1000 μSv per year. The maximum estimated dose to the public was 20 μSv per year.

This study also included an analysis of the causes and consequences of potential transport accidents involving vitrified and bituminous wastes and concluded that these transports do not represent a significant risk to the public or the environment.

Low-level and Intermediate-level wastes (LLW/ILW)

The radiation dose uptake during the transport of low and medium activity wastes in concrete moulds and metal drums from nuclear plants in France to the storage facility at Aube by both road and rail has been estimated in a 1992 study [12]. It was assumed that 32,000 packages per year would be shipped, 30% by road and 70% by rail.
By road the average distance was 350 km, 370 times per year, each truck containing two ISO containers. By rail each wagon would contain three ISO containers and 700 wagons per year would be sent to Aube, the average distance being 500 km.
Approximate collective doses in µSv per year were as follows;

	Rail	Road
Workers	150,000	80,000
Public	3,000	50,000

Individual doses are not available. However, collective doses for rail transport are stated to be much lower than for road transport. And, in the case of road transport the individual worker doses are less than 400 µSv per year and doses to the public are estimated to be less than 4 µSv per year.

Summary of Maximum Dose Uptake for Rail Transport (µSv per year)

Persons	Non-irradiated	Spent fuel	Waste (HLW)	Wastes (LLW/ILW)
Handlers	300	200	1700	
Crew	<4	<2	200	<400
Public	<1	<6	20	<4

Sea transport

A comprehensive study on the sea transport of radioactive materials was carried out by the National Radiological Protection Board (NRPB) in the UK in 1996 [13]. This included measurements of dose rates from cargoes and dose rates to crew, dockworkers and the public for fuel cycle materials as well as radionuclides.

Front end non-irradiated materials

These materials arrived in the UK either by RO-RO (Roll on – Roll off) ferries, LO-LO (Load on – Load off) container ships or combined RO-RO/LO-LO ships. Most consignments consisted of materials with Transport Index values of less than 50 although a few were as high as 300 for a trans-oceanic route. The specified segregation distances were easily met and it was common practice to load these cargoes remote from occupied areas. In RO-RO ferries vehicles were driven into rows on the lowest decks and on LO-LO ships containers were stacked either below or on deck. In mid-1996 shipments commenced of large numbers of cylinders of depleted Hex, each shipment consisting of 140 packages.
In 1994 imports of non-irradiated fuel cycle materials into the UK were about 7000 tonnes. In addition, some 9000 tonnes were in transit through UK ports. Non-irradiated fuel cycle materials were carried across the Atlantic on 10-20 day voyages or across the Pacific on 42 day voyages.

Back end irradiated materials

Spent nuclear fuel from LWR reactors has been transported by sea from Japan to Europe with over 170 voyages containing over 2000 flasks from 1970 to 2000. This transport was carried out in dedicated vessels. In addition there have been movements of spent fuel from Europe to the UK, initially in ferries and latterly in a dedicated vessel. This traffic increased over the 1990s at the time when shipments from Japan to Europe decreased.

Estimated doses for sea transport [13]

Exposure times for dockworkers and crew and passengers in regularly occupied areas and living quarters were estimated as well as transient and intermittent exposures.

Radiation surveys were also carried out on a range of vessels and cargoes and this included cabins, bridge areas as well as cargo areas. The results for three ferry vessels showed that in regularly occupied areas the dose rate was about 0.5 µSv per hour. On all other ferries dose rates were not measurable. For two UOC shipments dose rates in regularly occupied areas were 0.04 and 0.2 µSv per hour, the difference being due to different loadings.

The dedicated vessels carrying spent fuel gave readings of about 0.07 μSv per hour in the bridge area with a corresponding time of exposure of 600-1000 hours.

Using this methodology most crew and dock workers were estimated to have received annual doses of less than 100 μSv. Up to 20 crew members with duties within the cargo areas on longer trans-oceanic routes record doses of some 300 μSv per voyage. On short ferry voyages the critical group of drivers travelling weekly are unlikely to receive annual doses greater than 32 μSv. Members of the public travelling less frequently on ferries are unlikely to exceed annual doses greater than 10 μSv.

A survey of records of the exposure dose of workers engaged in the sea transport of spent nuclear fuel (and low-level waste) in Japan has also been made [14].

Estimated maximum doses to crew and passengers are listed below in μSv per year. These have been corrected for natural background.

Route	Material	Passengers	Crew
Cross-Channel	Radionuclides	30	25
Cross-Channel	Non-irradiated	2	25
Baltic/Arctic	Non-irradiated	0	25
Atlantic	Non-irradiated	10	10
Pacific	Non-irradiated	20	300
European	Irradiated	0	600
Pacific	Irradiated	0	680

Another study has been carried out to assess doses during manual cargo handling. In one year, three ships carrying UOC in transport containers (CTUs) docked and all unloading operations required manual handling for releasing tie-downs and twist-locks on containers. The consignments consisted of 25, 27 and 29 CTUs with dose rates of 10 – 20 μSv per hour at 1m. Individual dose meters were issued to selected workers for the duration of the cargo handing. The doses in μSv received by workers on board vessels during loading and discharge of containers are shown below.

Vessel	Cargo	Time spent	Dose received
Modern RO-RO	29 containers	4 h	10 – 12
Modern LO-LO	27 containers	8 h	~ 20
Older LO-LO	25 containers	2 – 6h	11 – 38

These results show that a dockworker, discharging a cargo of non-irradiated nuclear material (UOC) consisting of about 20 – 30 container units (CTUs) and requiring manual handling would receive between 10 and 30 μSv over a 6 hour period. With an average cargo of say 5 CTUs the dose is unlikely to exceed 5 μSv. Good supervision is needed to avoid unnecessary doses to workers and the public, for example, by keeping them away from CTU stacks whenever possible.

In Sweden irradiated fuel is transported in a dedicated vessel from nuclear stations to the storage facility. Some 80 flasks are transported per year and no member of the crew has received a dose greater than 1000 μSv per year (15).

Dosimetry data for six voyages between 1998 and 2000 in Pacific Nuclear Transport Limited (PNTL) ships transporting spent fuel from Japan to Europe (16) showed a maximum dose of 120 μSv per voyage.

A special study has also been carried out at the Barrow Terminal which is a dedicated port operated by British Nuclear Group (BNG) for handling spent fuel employing eight dockworkers. Individual dose meters are issued to these workers because their doses are 15 to 20 times greater than those encountered in other ports. Their work involves the close manual handling of spent fuel flasks prior to loading onto rail wagons for transport to Sellafield. Their annual workload is more than five times greater than for similar workers in other ports and the levels of exposure are around the target of 1mSv per year. This lends support to the assumptions made for all other groups of dock workers who handle fewer packages at lower dose rates.

High-level waste

Dose measurements [16] carried out during three shipments of HLW from Europe to Japan between 1999 and 2001 showed a maximum dose of 550 μSv per voyage which includes the return journey transporting spent fuel. It is unlikely that anybody would carry out more than one such journey per year.

MOX and plutonium

Dose measurements [16] carried out during two shipments of MOX and one of plutonium from Europe to Japan showed a maximum dose uptake of 160 μSv per voyage. Two such shipments per year are feasible giving a maximum dose of about 320 μSv per year.

Summary of Maximum Dose Uptake for Sea Transport (μSv per year)

Persons	Non-irradiated	Spent fuel	Waste (HLW)	MOX/Plutonium
Handlers	<300	<1000	<1000	<1000
Crew	<300	<700	<600	<200
Public	<20	<1	<1	<1

Dose Assessment Model

The data obtained from the study of the sea transport of nuclear fuel cycle materials [13] are very comprehensive and allow a dose assessment model to be developed which can be used to predict the doses likely to be received by dockworkers (the critical group) under a wide range of scenarios. For example, on a container ship transporting non-irradiated materials there would be one or two groups of dockworkers handling twist-locks and lashings etc. The dose received from a small cargo of, say, 5 containers would be about 10 μSv in less than 1 hour and for a large cargo of 25 containers about 30 μSv in about 4 hours. From the size of the port and the number of nuclear cargoes to be handled per year the annual doses to dockworkers could be estimated. So for, say, 1 cargo per month, 11 small and 1 large in the year, then the annual dose would be about 11x10 plus 1x30, i.e. 140 μSv. This model is considered to be robust and unlikely to be in error by more than a factor of two. It indicates that it is very unlikely that any dockworker employed in a general port (as opposed to a dedicated port such as the BNG operated Barrow Terminal) will exceed the target dose of 1000 μSv per year.

Air transport

Radiation doses to aircrew from the transport of radioactive materials are said [17] to be low because radioactive cargoes are well shielded by their own packages and are surrounded by other cargoes which provide additional shielding. Data [18] for a specific transport of plutonium/MOX by air from Europe to North America clearly indicates this. The result is that doses are low when compared with the dose received from natural radiation for aircrew members which is about 4000 μSv per year, i.e. about twice the average for members of the public. At present not sufficient data are available to draw conclusions for all materials transported. However, the number of air shipments of fuel cycle products is very small.

Summary of individual doses for nuclear fuel cycle materials

The expected maximum dose up-takes in μSv per year under normal conditions for the various materials and for the various modes of transport are summarised below.

Material	Persons	Road	Rail	Sea
Non-irradiated materials	Handlers Crew Public	300 100-700 <4	300 <4 <1	<300 <300 <20
Spent fuel	Handlers Crew Public	<1000 200-500 <4	200 2 <6	<1000 <700 <1
Waste (LLW/ILW)	Handlers Crew Public	 20-400 <4	 <400 <4	
HLW	Handlers Crew Public		1700 200 20	<1000 <600 <1
MOX/plutonium	Handlers Crew Public			<1000 <200 <1

Two recent surveys of the radiation exposure to workers and the public resulting from the transport of radioactive materials also include data for fuel cycle materials. The first [19] carried out on behalf of the European Commission covers the transport of a wide range of materials shipped in the EU and Applicant Countries mainly for the year 2001. The second [20] surveyed radiation exposure data associated with the transport of radioactive material in Germany. These surveys support the data in the above table on the radiation doses incurred by transport workers and members of public resulting from the transport of nuclear fuel cycle materials.

Collective doses

Although it is the individual doses to workers and the public which are of primary importance in transport operations, the collective dose, i.e. the sum of all the individual doses, is also of interest to the regulators. Data available [2] for collective doses for radioactive transport in the UK for 1989, summarised below, show that annual collective doses for nuclear fuel cycle transport in the UK was substantially less than that for radionuclide transport.

Collective dose man mSv per year		
Material	Workers	Public
Nuclear fuel cycle	31	27
Radionuclides	381	26

It should be recalled that the annual collective dose to the UK population from natural background radiation is over 100 million man mSv.

ALARA principle

The International Basic Safety Standards (BSS) require operators to reduce doses to as low as reasonably achievable, the ALARA principle, which is normal practice in the nuclear industry including the transport industry. For nuclear fuel cycle transport, the ALARA principle can be met by demonstrating that under normal operation dose up-take has been minimised and best practice adopted, for example in the segregation and storage of containers, the shielding of drivers, the supervision of working practices, operator training, etc. For nuclear fuel cycle materials the integrity of the package will ensure that the material is contained even under abnormal conditions.

Conclusion

Analysis of the data on dose exposure during the various modes of transport of nuclear fuel cycle materials indicates that it is very unlikely that any group of workers not classified as radiation workers or any member of the public will receive annual doses in excess of the limit of 1000 μSv (1mSv) under normal conditions.

This is important because all modes of transport for all nuclear fuel cycle materials then fall below the level of expected dose for which workplace or individual dose monitoring is required and the Radiation Protection Programme will not have to include this onerous provision.

For over 45 years transport organisations have safely and securely managed shipments of nuclear fuel cycle materials without any significant radiological impact on man or the environment. This record of success is a tribute to the effectiveness of the regulatory framework as well as the collective competence of the organisations involved in packaging and transport activities.

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Annex 1

Regulations for the Safe Transport of Radioactive Material

TS-R-1; 2005 Edition

Section III
GENERAL PROVISIONS

RADIATION PROTECTION

301. Doses to persons shall be below the relevant dose limits. Protection and safety shall be optimized in order that the magnitude of individual doses, the number of persons exposed, and the likelihood of incurring exposure shall be kept as low as reasonably achievable, economic and social factors being taken into account, within the restriction that the doses to individuals be subject to dose constraints. A structured and systematic approach shall be adopted and shall include consideration of the interfaces between transport and other activities.

302. A *Radiation Protection Programme* shall be established for the transport of *radioactive material*. The nature and extent of the measures to be employed in the programme shall be related to the magnitude and likelihood of radiation exposures. The programme shall incorporate the requirements of paras 301, 303-305 and 311. Programme documents shall be available, on request, for inspection by the relevant *competent authority*.

303. For occupational exposures arising from transport activities, where it is assessed that the effective dose:

(a) is likely to be between 1 and 6 mSv in a year, a dose assessment programme via workplace monitoring or individual monitoring shall be conducted;
(b) is likely to exceed 6 mSv in a year, individual monitoring shall be conducted.

When individual monitoring or workplace monitoring is conducted, appropriate records shall be kept.

EMERGENCY RESPONSE

304. In the event of accidents or incidents during the transport of *radioactive material*, emergency provisions, as established by relevant national and/or international organizations, shall be observed to protect persons, property and the environment.

305. Emergency procedures shall take into account the formation of other dangerous substances that may result from the reaction between the contents of a *consignment* and the environment in the event of an accident.

TRAINING

311. Workers shall receive appropriate training concerning radiation protection including the precautions to be observed in order to restrict their occupational exposure and the exposure of other persons who might be affected by their actions.

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