APPLYING ALARA TO THE DECONTAMINATION OF IRRADIATED NUCLEAR FUEL CONTAINERS

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ABSTRACT

Prior to shipment, the levels of non-fixed contamination on the surface of packages containing radioactive materials must be less than the limits specified in the International Atomic Agency's transport regulations[1]. Some packages, such as flasks used to transport irradiated nuclear fuel (INF) are prone to become contaminated during loading and require subsequent decontamination. Decontamination operations and monitoring surveys involve some occupational radiation exposure. During 1998, surveys of railway wagons and irradiated nuclear fuel flasks in France revealed some excessive levels of contamination. This led to the cessation of these shipments for a period in several EU Member States including France, Germany and Switzerland. In the follow up period, extensive surveys and investigations were carried out to establish the causes, nature and magnitude of the contamination, and to seek remedies[2]. These circumstances had an impact throughout the European Union (EU), and more thorough decontamination and monitoring procedures were introduced. In some cases, this led to increased exposures of the workers carrying out these duties. These events have raised the question of how to ensure the optimisation of radiation protection while maintaining levels of non-fixed contamination below regulatory limits. Information, data and experience from four Member States of the EU were reviewed to investigate this issue. Investigations in France into flask monitoring and preparation for transport showed that considerable dose saving could be achieved by modifications in work procedures.

INTRODUCTION

This paper summarises the findings and conclusions of a study[3] undertaken to assess the potential for the application of the ALARA principle to the decontamination of irradiated nuclear fuel transport flasks (or casks) and equipment. The project[3] was part funded by the European Commission (DG TREN) and various national agencies and the work was performed by NRPB, GRS, Transnucleaire/ NUSYS, NRG and CEPN.

Nuclear fuel transport flasks may become contaminated with radioactive materials on both internal and external surfaces when loading or unloading fuel, from contact with water in the fuel storage ponds at nuclear installations. This effect has been well known and reported over several decades[4-8]. Surface contamination on transport packages/flasks or equipment is defined in the latest Transport Regulations of the International Atomic Energy Agency[1], as the presence of radioactive material on a surface such that the activity per unit surface area is in excess of 0.4 Bq cm^{-2} for beta/gamma-emitters and low-toxicity alpha-emitters and 0.04 Bq cm^{-2} for all other alpha-emitters. These Regulations[1] also require that the non-fixed contamination on the external surfaces of packages/flasks must be kept as low as practicable and, under routine conditions of transport, must not exceed the limits of 4 Bq cm^{-2} for beta/gamma-emitters and low-toxicity alpha-emitters and

0.4 Bq cm^{-2} for all other alpha-emitters. These limits are applicable when averaged over any area of 300 cm^{2} of any part of a package/flask surface. The exterior surfaces of conveyances are subject to the same requirements but the internal surfaces of dedicated conveyances under exclusive use have no derived limits for non-fixed surface contamination.

Fixed contamination is that contamination which cannot be removed during normal conditions of transport. The fixed external surface contamination of conveyances and transport equipment is controlled by the resulting radiation dose rate that must be less than 5 μSv h^{-1}. Transport conditions and handling operations such as vehicle vibration, abrasion and weathering can modify the nature of fixed surface contamination such that it may become non-fixed surface contamination. This is a phenomenon generally known[7,9-11] as "sweating" or "weeping" or as "hide-out". Surface radioactive contaminants may subsequently be transferred from a flask to the transport equipment, conveyances and the transport personnel or be dispersed in areas accessible to the public.

Contamination surveys of flasks, wagons and associated equipment are undertaken on the plant premises or on the transport route. Decontamination and monitoring operations may be necessary to ensure that the contamination levels are below the regulatory limits. Workers carrying out these operations may receive radiation exposures from the package contents, and potentially from any surface contamination present. These exposures may be received while the workers are actively carrying out those procedures, or while in the immediate vicinity of the package carrying out associated duties, for example administrative work.

OBJECTIVES OF THE STUDY

The radiation protection principles underlying the IAEA Transport Regulations[1] require that radiological protection in transport shall be optimised 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 (ALARA), economic and social factors being taken into account. Also, the doses to persons must be below the relevant dose limits. The ALARA principle was developed and published by the International Commission on Radiological Protection[12, 13] (ICRP). ICRP has provided further guidance on the application of optimisation to the radiation protection of workers[14].

The main objective of the study[3] was to assess and evaluate the application of the ALARA principle for controlling flask surface contamination in the transport of irradiated nuclear fuel shipments. The contamination management strategies generally available to plant operators may in broad terms be divided in three categories: prevention, decontamination and minimisation[15.] In the present context, prevention and decontamination relate to operational practices and procedures, whereas minimisation of contamination pertains primarily to design-related issues at the planning stage of a facility, operation or flask. Information was collected for analysis, and comparison, from the four participating countries. These collected data included incidence of contamination, exposures of workers involved in the transport operations, and techniques adopted to reduce contamination incidence and exposures.

SOURCES OF CONTAMINATION

Transport flask surface contamination arises mainly from dissolved or particulate radioactive materials in the storage and cooling pond water. These materials are activated corrosion products from the primary reactor cooling cycle and fission or activation products from the fuel elements. Surface contamination of flasks may also occur by direct contact with the irradiated fuel elements. The extent and magnitude of surface contamination is also dependent on the concentrations and chemical forms of the radioactive constituents in the pond water, and the contact time in the pond.

On UK flasks and wagons, the main potential contaminant is Cs-137. This radionuclide is a soluble fission product, leached from spent fuel rods through stress-related pin holes in the fuel cladding whilst fuel elements are kept in the cooling ponds at each nuclear power plant (NPP), prior to despatch to the reprocessing factory or storage site. In most UK NPPs, fuel elements are loaded into a 'skip' - an open-topped steel basket used to transfer elements into flasks. Generally, this takes place by immersing the flask into the pond water and this gives rise to flask surface contamination. Unlike flask surfaces, skips are not decontaminated, since they are held within the flask until delivered to the reprocessing site or returned to the NPP. Skips can be significant contributors of pond water activity and the more contaminated skips are frequently returned as rapidly as possible without delayed immersion in the ponds.

In pressurised and boiling water reactors (PWRs and BWRs), the main contaminants are the activated corrosion products Co-60, Ag-110, or Mn-54 and the fission product Cs-137. In France the activity of the pond water has been reported up to 400 MBq m^{-3}. In order to limit occupational exposure during down-time, a special water chemistry treatment occurs just before a planned shutdown; this is to precipitate a large fraction of the corrosion and activation products. However, this is a major cause of deposition of particles on the fuel assemblies. In France, there are two main systems used for loading spent fuel into flasks, depending on the NPP type. The flask may be immersed in the pond or connected to the underside of the pond. The main surfaces of the flask are covered during these operations, but there are phases in both of these processes when pond or leakage water can contaminate parts of the flask surface.

EXPERIENCE OF CONTAMINATION ON INF FLASKS

Despite the extensive effort involved in cleaning and monitoring, non-fixed excess surface contamination has been found to occur occasionally on shipments of irradiated nuclear fuel (INF) transport equipment (both flasks and conveyances) at the final destination of the spent fuel transport. Some examples of incidence are given in Table 1. An INF flask is routinely sampled at many points across its surface and each point is usually tested by wiping an area of 300 cm^2 of the surface. The wipe test is generally assumed to remove 10% of any non-fixed contamination, although reviews and research programmes suggest that the removal factor is likely to be a much higher percentage for most such wipes. Therefore, the assumed removal fraction is likely to lead to an upper estimate of the surface contamination level.

Table 1: Examples of excess contamination incidence

Shipment operations	Number of flasks	Number/ percentage of flasks or wagons with excess contamination
France: Arrivals at Valognes rail terminal, 1997, from EDF NPPs[2]	207	55 flasks (27%) (typical of previous decade). 43 wagons.
Germany: Empty INF flasks arriving from COGEMA, 1988-1998[3]	645	5% flasks. 1% wagons.
Netherlands: Loaded flasks to COGEMA, 1989-1996[3]	110	4.5% flasks. 0% wagons.
UK: Annual shipments of loaded and unloaded flasks between NPPs and reprocessing plant[3].	1200	1% (approx.) flasks. <1% wagons.

During 1998, it was disclosed that excess contamination had been found on flasks and wagons used to transport irradiated nuclear fuel from NPPs in France, Germany and Switzerland to La

Hague. This resulted in temporary cessation of these shipments. After comprehensive analyses on the causes and consequences of INF flask contamination many improvements were made to the operations involved with flask preparation, cleaning, monitoring and maintenance. These improved contamination control measures include:

- use of a protective cover and vinyl overskirt during wet loading of flasks (in some NPPs adhesive film or peelable paint is used instead of the overskirt),
- reduced contamination levels in preparation areas,
- monitoring control checks by independent organisations,
- improving ALARA awareness among the workforce.

The measures adopted have resulted in a much lower incidence of excess contamination on flasks being moved to, from and within France. Excess contamination in Western Europe currently occurs on about 1% or less of all flask movements whether loaded or empty.

EXPOSURES FROM DECONTAMINATION AND MONITORING

Radiation exposures from flask surface contaminants are generally not considered a significant hazard to persons[2,7]. More significant is direct radiation emerging from the INF flask, both gamma and neutron radiation. Thus, the study was mainly focused on worker doses.

Netherlands

Worker exposures were collected for transport operations to and from the two NPP sites at Dodewaard and Borssele, during the period 1988 to 1996. The collective exposures at the two NPPs per shipment were 2.1 man mSv and 1.25 man mSv respectively, for all loading, preparation and monitoring operations.

UK

Irradiated fuel is transported from gas-cooled Magnox and AGR NPPs in the UK to a reprocessing plant, and discharged flasks are returned to the NPPs. Exposure rates associated with flasks containing spent Magnox and AGR nuclear fuel remain low, typical maxima of about 10 and 40 μSv h^{-1} at 1 m, respectively. This accounts for manual cleaning being preferred in the UK. The same situation with (non-UK) BWR and PWR flasks involves exposure rates up to some 200 and 400 μSv h^{-1} at 1 m, respectively. The numbers of workers involved in one flask operation is from 1 to 4. The annual doses from cleaning and monitoring are below 1 mSv apart from workers directly involved with preparation of the loaded flask where annual doses may be a few mSv.

France

Average dose rates at 1 m from the sides of loaded INF flasks from NPPs in France are typically about 100 μSv h^{-1}. Data obtained for the study[3] indicated collective doses for UO2/ MOX flask preparation and monitoring of 6.2 man mSv and 2.0 man mSv, respectively, per flask operation.

Germany

In Germany maximum dose rates at the external surfaces of conveyances carrying loaded INF flasks are typically in the range from 10 - 1000 μSv h^{-1} with an average maximum of about 100 μSv h^{-1}. The typical collective dose for loading, cleaning, monitoring and preparation for despatch from a NPP is about 3 man mSv per flask. Some 30 to 40 workers in total are involved in these operations and individual doses (gamma and neutron) from flask cleaning, monitoring and preparation range up to about 0.8 mSv per flask. Following the contamination events discovered in

1998, enhanced monitoring requirements were introduced and the collective dose for these operations are estimated to increase to about 4.5 man mSv per flask. Increased exposures have also been observed in France for these reasons.

DOSE REDUCTION TECHNIQUES

Ideally, equipment and systems should be designed with full consideration of dose optimisation but even with existing systems, some dose reduction can be achieved by modifying existing equipment, practices and procedures. The methods reviewed in the study[3] are listed here.

Reduction in the formation of contaminants

Since in many types of NPP, contamination in pond water originates from stress-related pin-holes in fuel element cladding, a possible solution would be to strengthen the cladding but it is unlikely after some 50 years of reactor fuel design and operation that the design has not already been optimised. Therefore, there are unlikely to be any cost-effective changes that could be made to current designs that would reduce contamination levels.

Removal of contamination from the storage/loading pond water

Contamination may be removed from the loading ponds by cleaning or filtration. However, both of these operations will result in worker exposure and will produce radioactive waste that will require either storage or disposal. In some NPPs, contamination on the skips used to hold the fuel elements has been found to be a significant factor in controlling pond water activity. The introduction of skip cleaning and maintenance facilities can yield reductions in pond water activity, but further investigations are required to determine whether such actions would be dose- and cost-effective.

Modification of cleaning/monitoring procedures

The number of decontamination and monitoring operations should be reviewed. It may be possible to minimise the number of operations, while still ensuring that the contamination levels are below the relevant limits before and during shipment. Further reductions in worker doses may be possible by the use of remote decontamination procedures rather than manual operations. Also, additional shielding might be employed. In addition, other preventive measures such as thoroughly wetting the flask before it is lowered in the pond or the use of protective covers would reduce the effort needed for cleaning operations after loading.

Protection of contaminated flasks during transport

The use of canopies/ covers over irradiated fuel transport flasks during carriage is common in many countries. The covers protect the flasks from the effects of weather particularly wind and rain, and restrict unauthorised access to the surfaces of the INF flasks during transport.

Design of containers to limit contamination

The effort of decontaminating surfaces should be considered during the design stage of INF flasks. However, there may be competing requirements such as the number and design of cooling fins for heat removal.

OPTIMISATION IN PRACTICE

ICRP[14] recommends that the resources devoted to the control of a hazard should be broadly commensurate with the magnitude of that hazard. Radiation protection is optimum only when the deployment of further resources to reduce the radiation detriment would be unwarranted by the reduction of the hazard that would be achieved. Optimisation of radiation protection generally requires the weighing of the costs of the protection measures for the group of workers involved against the reduction in doses achieved. This weighing is most often done with the help of a monetary value of the collective dose[16, 17]. In recent years there has been an increasing emphasis placed on workplace management as the principle means of implementing optimisation in an operational context, as recommended by ICRP[14]. In practice, optimisation through work place management may take the form of common sense methods for minimising exposure.

For this project[3], a detailed study was provided by CEPN of the work patterns associated with flask preparation, cleaning and monitoring at some NPPs in France. The study was conducted with a view to examining those work areas where general lessons could be learned on methods for dose saving. Specific preparation and contamination monitoring operations (at a 900 MWe UO_2 plant) were analysed to determine their contribution to the overall occupational collective dose arising from these flask operations, and these are shown in Table 2.

Table 2 Contribution of various operations to overall collective dose

Operation	Duration (h)	Duration (%)	Collective dose contribution (%)
Tools transfer Transfer of hoses and tools.	25.0	16	2
Unloaded package reception Monitoring for contamination Package preparation Cover and adhesives fitting	30.9	20	6
Loading Loading and subsequent monitoring	26.9	17	7
Preparation before shipment Removing protective cover and adhesives. Emptying/ draining/ drying. Leak-tightness monitoring	68.6	44	74
Decontamination	4.5	3	11
Monitoring at railway terminal	0.2	0.1	0.0
Others	0.4	0.2	0.1
Total (rounded)	156	100	100

Some three-quarters of the collective dose is incurred during the preparation of the flask, after loading and before decontamination. A further 11% is from decontamination. It was concluded that the tasks associated with the prevention, elimination and monitoring flask surface contamination accounted for 42% of the overall collective dose.

The detailed operations were examined and ways to reduce exposures were identified. The most significant of these are listed in Table 3. In addition to consideration of the overall collective dose, the potential collective dose savings from separate operations were examined. It was concluded that some 40% of the preparation collective dose could be saved, along with 21% of that from monitoring. Overall, of the average collective dose per flask shipment (5.3 man mSv) from all flask preparation and monitoring operations, up to 36% could be saved. It was found that there was unnecessary exposure, especially from the contaminated equipment used (e.g. the liquid-vapour separator) and from unnecessary time spent in the vicinity of the flask. The latter includes time spent by a second operator during wipe testing and carrying out administrative duties. Performing most decontamination while the flask was still full of water would also save exposure due to the increased shielding available. Use of some remote equipment would also help to reduce exposures. Time spent applying adhesives to protect silicone seals from pond water will be eliminated when the programme to replace those seals has been completed. Although these estimated dose savings are in the context of practices at the French NPPs studied, it is likely that similar considerations will apply in other types of NPPs.

Table 3 Potential dose savings from optimised flask cleaning, monitoring and preparation operations

Protection action	Potential collective dose savings, %
Liquid/vapour separator shielding	9
Elimination of special adhesives (to protect seals)	8
Decontamination operations with full cavity	6
Shield operator's desk from radiation	4
Remote display devices in the protected desk	2
Removal of the liquid/vapour separator from the draining orifice	3
Reduction of waiting time / time spent near flask	*2*
Discontinuation of double monitoring (fin and caisson area)	*2*
Total potential dose saving	36

Dose savings from monitoring operations are shown in italic.

CONCLUSIONS

The routine exposure of workers from the movement of irradiated nuclear fuel flasks is generally low, and the exposure of members of the public is trivial. The majority of this exposure is due to direct radiation from the contents of the flask. During movement between installations, contamination on the surfaces of flasks results in trivial exposures from the contamination, by direct exposure and from inhalation and ingestion. Most of the exposure associated with INF flask transport is from the preparation and monitoring of irradiated nuclear fuel flasks and this radiation exposure of workers can be optimised based on the operational data.

Operators must comply with the transport regulations and must ensure that fuel flasks and associated equipment comply with surface contamination requirements. The contamination control strategies of prevention and decontamination are routinely applied. If new equipment is to be designed, then contamination issues can be considered at the planning stage. Much can be achieved at the design stage particularly through the use of engineered controls. For equipment/ facilities already in use, appropriate changes to operational procedures may be considered. The contamination of nuclear fuel flasks can be mitigated by various operational procedures. A comprehensive study of worker exposures at French NPPs was carried out for this project and the findings of that study could be applied to similar operations at other NPP types. It was found that there is an important contribution to individual worker dose from the preparation and monitoring of spent fuel shipments.

The following protective actions would help to reduce exposures during the preparation phase:

- Decontamination with flask cavity water filled,
- Decontamination, shielding or removal of contaminated tools and equipment,
- Reduction of worker's unnecessary occupancy time in radiation area and/or relocation of the waiting area.

The following monitoring operations would result in reductions to collective dose:

- Handling of the wipe tests by a single operator,
- Reduction in worker occupancy time in radiation areas between wipe tests and/ or relocation of the waiting areas.

The cost of reorganising a method of working may be low whereas the cost of equipment and facilities can be high. Each site should examine the available options for dose reduction.

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