ANALYSIS OF THE DOSES ASSOCIATED WITH THE SPENT FUEL SHIPMENTS FROM THE FRENCH NPPS: ARE THEY ALARA?

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1 Introduction

The spent fuel shipments from the French Nuclear Power Plants to the La Hague reprocessing plant have always been subject to significant efforts devoted to the prevention and elimination of the non-fixed contamination of the flask surface during their preparation (loading and cleaning) and the workers involved in those tasks receive annual individual dose levels that may be significantly higher than the average. Moreover, these shipments are subject, since 1998, to a reinforced procedure of monitoring of the contamination.

For these reasons, the French electricity utility Electricité De France (EDF) has initiated several studies, performed with CEPN, aiming to obtain a better knowledge of the individual and collective doses associated with the preparation and the monitoring of these shipments:

- A statistical study (from June 1999 to June 2000) has analysed the dosimetric results of the survey of one hundred shipments to La Hague,
- Two extensive measurement campaigns (in 1999 and 2000) have been conducted in order to evaluate the duration and dose-rates associated with each elementary operation involved in the preparation and the monitoring before shipment of a reference flask.

These studies allowed:

- To gain a better knowledge of the distribution of the gamma and neutron doses received during the cask preparation and the contamination monitoring operations, as well as the influence on these doses of the reactor model (900 MWe/1300 MWe), the fuel type (UO_2/MOX), and the thermal residual power of the assemblies.
- To determine the relative contributions of the main operations, irradiation sources and workplaces to the collective dose, with a specific focus on the operations associated with the prevention, elimination and monitoring of the contamination.
- To identify a set of radiological protection options and past experience analysis that could be envisaged in order to reduce as low as reasonably achievable (ALARA) the collective dose associated with the preparation and monitoring of the spent fuel tasks before their shipment from the NPPs.

Finally, the results of these studies have been used within the framework of a study conducted for the European Commission DG TREN [1], [2].

2 Statistical study of the French shipments dosimetry

2.1 Collective dose variability

As may be seen in Table 1, the statistical distributions of the gamma and neutron collective doses received during the preparation of the cask before shipment (empty cask preparation, fuel loading, cask internal cavity emptying, drainage and drying, decontamination of the cask external surface, cask handling) and the final monitoring against contamination (in the fuel building, on the lorry and on the railway wagon) presented an important variability within the sample under study.

Table 1: Statistical distribution of the collective dose per shipment (all shipment types taken together)

Variable		Average (man.mSv)	Standard deviation (man.mSv)	Max (man.mSv)
Preparation	gamma	4.0	2.1	9.9
	neutron	1.2	1.0	6.0
	Total	5.2	-	-
Monitoring	gamma	0.5	0.2	1.2
	neutron	0.8	0.5	2.3
	Total	1.3	-	-
Total		6.5	-	-

- Not estimated (not enough data)

2.2 Influence of the shipment characteristics

As a result of the statistical analysis of the data, a part of this variability could be explained by the influence of the shipment type[1]: reactor model (900 MWe/1300 MWe), loading type (dry/wet) and fuel type (UO_2/MOX), as shown in Figure 1.

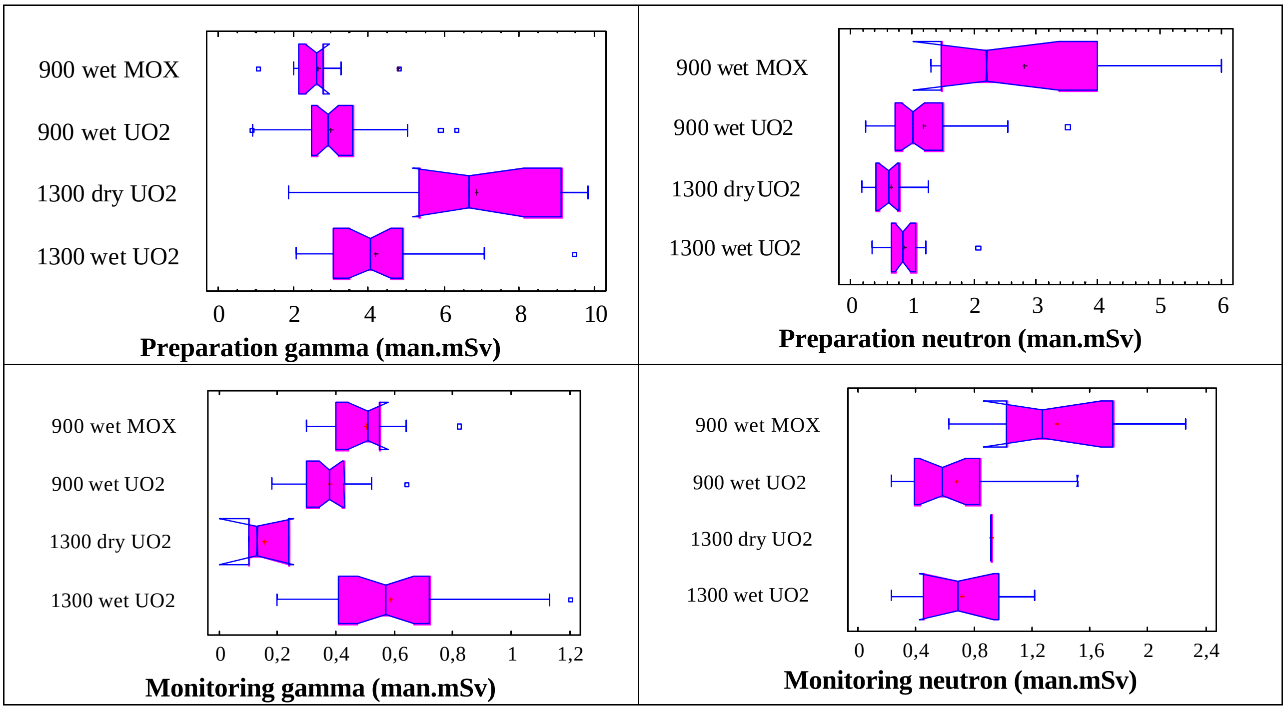


Figure 1: Statistical distribution of the collective dose per shipment, by shipment type (man.mSv)

The analysis of the influence of the shipment type has put in evidence that:

- the gamma collective dose received during the preparation of the cask was the highest in the 1300 MWe reactors (especially for those using the dry loading) and that the neutron collective dose received during either the preparation or monitoring of the casks was significantly higher for the shipments involving MOX fuel.

[1] In some reactors of the 1300 MWe model, the casks are loaded under water in a loading pit (wet loading) while in some others, they are loaded with no contact of the cask surface with water (dry loading); a "UO_2" shipment involves 12 UO_2 assemblies, while a "MOX" shipment involves only 4 MOX assemblies, surrounded by 8 UO_2 assemblies.

- in contrast, nor the type of protection used before loading (vinyl cover/3M adhesive) nor the type of package (TN12/LK100) did show any significant influence on the dosimetry.

However, the collective dose for each shipment type presents an important residual variability from one shipment to the other.

2.3 Influence of the thermal residual power of the assemblies

As a result of a regression analysis, a part of the residual variability of the collective dosimetry within each shipment type could be explained by the influence of the variability of the residual thermal power of the irradiated fuels - total residual power for the UO_2 shipments, residual power of the UO_2 or MOX assemblies for the MOX shipments - taken here as a first indicator of the variability among the shipments of the dose rates around the cask.

If the influence of the residual thermal power on the neutron collective dose was found significant for most of the shipment types (6 out of 8), it was almost never the case (only 2 out of 8) for the gamma collective dose. This observation has been found coherent with the fact that the contribution to the gamma collective dose of irradiation sources external to the cask (coming from contaminated tools and/or from the liquid/vapour separator used for the drainage and drying of the cask internal cavity) is significant during the monitoring against contamination and may be predominant during the preparation of the shipment.

However, the influence of the thermal residual power does not explain usually more than the half part of the variability of the collective dose from one shipment to the other, for a given shipment type. Even after taking into account the sources of variability presented above, the residual variability of the collective dose from one shipment to the other remains important and is probably due to the influence of other parameters - not studied here - such as the site, the way of performing the tasks (different from one operator to the other) as well as the possible occurrence of mishaps during some shipments.

2.4 Expected collective dose per shipment type and thermal residual power range

This statistical study has allowed to estimate, for each phase of the shipment (preparation, monitoring) and radiation type (gamma, neutron), as well as for each shipment type (reactor model, loading type and fuel type) and - if pertinent- level of thermal residual power:

- the expected average value of the collective dose per shipment; this value could be used to derive dosimetric objectives depending on the shipment characteristics,
- the limits of the 60% statistical "tolerance interval" for the collective dose per shipment (i.e. the intervals inside which one expects to find – with a 95% probability – 60% of the collective dose values for a shipment of a given type); these values could be used to identify and study particularly the shipments that present dosimetric results significantly distant from other shipments of same type (and thermal residual power range, if pertinent), i.e. the shipments that are the most and the least efficient from the dosimetric point of view.

Figure 2 presents the results of such an estimation for the shipment of UO_2 fuel from a 900 MWe reactor, where: the expected average value is given by the central regression line; the upper and lower limits of the 60% "tolerance interval" are given by the two other curves; the three shipments that are the most and least efficient from the dosimetric point of view are indicated by an arrow.

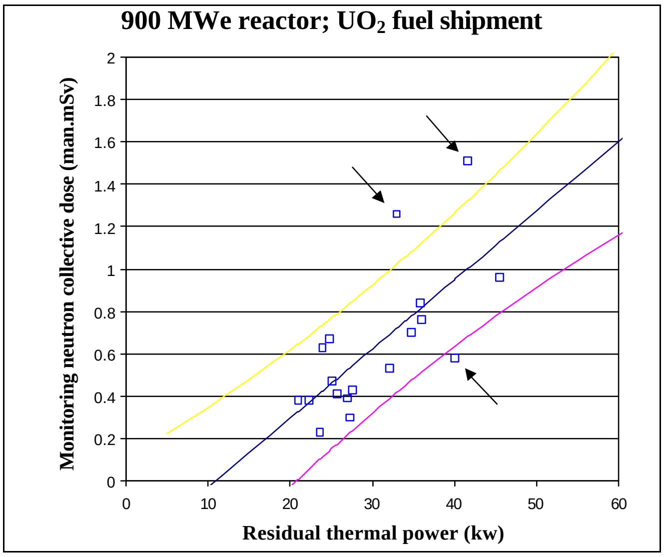


Figure 2: Linear regression between monitoring neutron collective dose and residual thermal power (900 MWe reactor, UO_2 fuel shipment)

2.5 Dosimetric stakes of the preparation and monitoring of the spent fuel shipments

2.5.1 National annual collective dose

The simple multiplication of the average collective dose per shipment by 200 shipments per year has led to a crude estimate of the annual collective dose associated with the preparation and monitoring against contamination of the irradiated fuel casks before shipment, shown on Table 2.

One should note that the resulting annual collective dose of 1.3 man.Sv is not negligible for it corresponds broadly to the annual collective dose associated with the operation and maintenance of one average French reactor and to a little less than 2% of the annual collective dose associated with the operation and maintenance of all French reactors.

Table 2: Estimate of the national annual collective dose associated with the preparation and monitoring against contamination of the spent fuel casks before shipment

		Collective dose (man.Sv/y)
Preparation	gamma	0.8
	neutron	0.2
	Total	1.0
Monitoring	gamma	0.1
	neutron	0.2
	Total	0.3
Total		1.3

2.5.2 Annual individual dose

The analysis over 10 months of the individual doses of the Chinon B operators has shown that the monitoring against contamination of the spent fuel shipments represents only a small fraction (0.5 mSv/y out of 3 mSv/y, i.e. 16%) of the annual individual dose of the radiation protection department operators involved at least once in the year in the monitoring of a spent fuel shipment, while the preparation of these shipments represents almost the half part (2.5 mSv/y out of 5.7 mSv/y, i.e. 44%) of the annual individual dose of the general services operators involved at least once in the year in the preparation of a spent fuel shipment.

This analysis has also shown that the difference between the total annual individual dose of the general services operators and the radiation protection department operators (2.7 mSv/y) is due to a great extent to their participation in the preparation of the shipments

3 Analytical dosimetric study of the preparation and monitoring of a spent fuel shipment

This study had as an objective the analytical assessment of the dosimetric cost associated with the operations of preparation of the flask and final monitoring of the contamination in order to identify potential protection actions. This assessment has been performed on the basis of measurement campaigns - operation per operation - of the equivalent dose rates and working duration.

3.1 Preparation

3.1.1 Description

The operations associated with the preparation of a flask before shipment extend over several days and include the following steps:

- Tools transfer: The control module (Figure 4 A) necessary to the emptying, drainage and drying of the flask together with some hoses and connection tools, are moved from one fuel building to the other, monitored against contamination and, if necessary, decontaminated.
- Package reception: The empty flask is received and checked against contamination at level 0m of the fuel building. The package is then hoisted towards the preparation pit, prepared for loading and protected against contamination by a water-filled protective skirt above the fins, adhesives on the rear and front end of the cask (Figure 3A), and placed inside a vinyl cover (Figure 3B).
- Loading: The package is placed under water into the loading pit (Figure 4G) and loaded with the spent fuel assemblies. The assemblies are then carefully monitored and the cask is closed.
- Preparation before shipment: The cask - loaded with the assemblies and filled with pond water - is moved from the loading pit to the preparation pit and its protections (vinyl cover and protective adhesives) are unfitted (Figures 3C and 3D). After a rapid decontamination of the cask, the preparation of the cask before shipment (as such) starts and will extend over several days. As the French casks do not allow, for safety reasons, transportation of the spent fuel assemblies without the complete elimination of the inside pond water, the cask must be emptied, drained and dried carefully, with the help of a control module (mobile module containing the pumps, valves, as well as measurement and display devices, Figure 4A), a liquid/vapour separator (Figure 4D), as well as several connecting tools and hoses (Figures 4B, 4C, 4D). It is then subject to extensive leak tightness monitoring (Figure 4E), at the end of which the skirt is emptied and removed and protective adhesives put in place (Figure 3G). The cask is then taken down to the 0m level of the fuel building and ready for shipment, after the putting in place of the shock absorbers on its front and rear ends.
- Decontamination: Decontamination of the whole cask surface (Figures 3E and 3F) takes place at least once in a shift during all the preparation operations.
- Monitoring at the railway station: Package is shipped after the end of monitoring against contamination at the railway station (Figure 4H).

3.1.2 Contribution of preparation steps to the collective dose

Table 3, that presents the working duration, average dose rate and collective dose associated with each of the preparation steps, shows clearly that the operations dealing with the preparation before shipment and the decontamination of the cask, that represent less than the half part (47%) of the working duration, contribute to the most part (85%) of the collective dose, due to the significant average dose rate to which the workers are exposed during these operations.

Table 3: Collective dose associated with the various steps of the flask preparation (900 MWe, UO_2)

Operation	Duration (h)	Duration %	Dose %	Average dose rate (mSv/h)		
			Gamma + Neutron	Gamma	Neutron	Gamma + Neutron
Tools transfer	25.0	16%	2%	2	0	2
Package reception	30.9	20%	6%	7	0	7
Loading	26.9	17%	7%	8	0	8
Preparation before shipment	68.6	44%	74%	19	15	34
Decontamination	4.5	3%	11%	34	44	78
Monitoring at railway terminal	0.2	0.1%	0.0%	0	0	0
Others	0.4	0.2%	0.1%	3	2	5
Total	**156.4**	**100%**	**100%**	**12**	**8**	**20**

3.1.3 Contribution of working areas to the collective dose

The working areas that contribute the most to the collective dose are: the working areas close to the cask (51% of the collective dose), mainly for the relatively high dose rate present in these areas, coming as well from gamma and neutron radiation; the circulation areas and working areas back from the cask (34% of the collective dose) for which the exposure comes essentially from the large time spent in these areas and where the dose rate results mainly from the gamma radiation; the other zones (15% of the collective dose) whose contribution comes also essentially from the large time spent in these areas and where the dose rate results also mainly from the gamma radiation.

3.1.4 Contribution of the most important operations to the collective dose

The operations that contribute mostly to the collective dose are, on the one hand, the operations associated with the prevention and elimination of the contamination and, on the other hand, those associated with the flask preparation, that contribute respectively to 29% and 34% of the collective dose.

Regarding the collective dose associated with the prevention and elimination of the contamination: 11% comes from the decontamination operations, of which the most part (90%) is due to the decontamination operations performed after emptying the internal cavity of the cask, during which the average dose rates are much higher (respectively 2 and 7 times higher for gamma and neutron) than the dose rates at the same locations before emptying the cavity; 10% comes from the fitting and unfitting of the adhesives, of which almost 90% is due to the fitting of ill-suited cut adhesives during the followed up campaign; 8% come from the fitting, rinsing, and unfitting of the vinyl cover, of which the most part (80%) is due to the unfitting of the cover after loading.

Regarding the collective dose associated with the flask preparation, 14% comes from the flask tightness monitoring, of which a third is due to the gamma radiation from the contamination of the draining tool; 8% comes from the emptying and removal of the skirt, of which almost the half part (43%) is due to the gamma radiation coming from the contamination of the liquid/vapour separator during the rinsing of the later with the hot water drained from the skirt; 6% comes from the draining and drying of the internal cavity, of which almost three quarter (73%) is due to the gamma radiation from the separator and the draining tool that are permanently present during the drying of the internal cavity, that represents 64% of the collective dose of these operations; 6% comes from waiting times and forms filling, whose contribution to the collective dose is mainly due to their important duration that represents 20% of the total duration of operations, and of which more than 80% are received at a desk, located a few meters away from the cask inside the fuel building.

A specific attention has been devoted to the operations concerning the liquid/vapour separator, that contribute to 6% of the collective dose, of which 44% is received during the rinsing of the separator while 20% come from the monitoring and emptying of the separator during the draining of the cavity.

3.1.5 Possible protection actions

On the basis of the analysis of the contributions presented above, a set of possible protection actions has been identified and their potential dosimetric savings have been evaluated: liquid/vapour separator shielding (<11%), decontamination only with full internal cavity (<7%), protecting the desk from radiation (5%), remote display devices in the protected desk (2%), elimination of special adhesives for protection and transport (10%) or use of well-suited adhesives for transport (5%), removal of the liquid/vapour from the draining orifice besides which a lot of operations take place (4%), forms filling outside the fuel building (3%), early exit of the operators at the end of operations (2.5%), remote monitoring and emptying of the liquid/vapour separator (1%), systematic decontamination of the immersion tool (<0.5%).

The maximal potential dosimetric savings associated with the implementation of all these protection actions (among which some are mutually exclusive) has been estimated to 40% of the collective dose associated with the preparation of the cask before shipment.

3.2 Monitoring against contamination

3.2.1 Description

The monitoring of the cask's surface against contamination begins after completion of the cask's preparation and includes several monitoring steps: in the preparation pit of the fuel building, on the lorry and on the railway wagon (the second step being omitted when the NPP is directly connected to the railway network).

Monitoring in each step consists of both one screening test for each location defined in the harmonised procedure (covering the totality of the accessible zones of the cask, with the exception of the cooling fins, thousands in number) and one 300 cm^2 smear test for each of the same locations. Monitoring on the lorry and at the railway station include as well screening tests and smear tests of the accessible parts of the vehicle. All these tests are successively performed by two teams: one from the NPP radiation protection department and one from an independent organisation (double monitoring). The total number of 300 cm^2 smear tests performed for each shipment is thus equal to 422.

Finally, regulatory dose-rate measurements (at contact and 1-meter away from the cask) are performed two times: once before the shipment of the lorry and once before the shipment of the railway wagon.

3.2.2 Contribution of the monitoring steps to the collective dose

The study of the relative contribution to the collective dose of each step of (double) monitoring against contamination, has shown that the contribution to the collective dose of the first step (in the fuel building) is almost equal to the double of each of the two other steps (on the lorry and on the railway wagon). This difference is essentially due to the difference in duration between these steps, that does not come only from the number of smear tests but also from the sequence of operation, waiting and handling phases within each step.

3.2.3 Contribution of operations to the collective dose

The study of the relative contribution to the collective dose (all monitoring steps together) of the various monitoring operations has shown that 90% of the collective dose was associated with the monitoring operations as such (front part (29%); rear part (30%); waiting /circulation (21% of the dose for 63% of the duration); Fins zone (7%); lorry and wagon (4%) and that only 10% of the collective dose were received during operations that were not directly related to contamination (regulatory dose rate measurements (7%) and seals affixing (3%)).

3.2.4 Monitoring dose and residual contamination risk by monitoring zone

The comparison, for each monitoring zone, of the collective dose associated with the monitoring and the residual risk of finding contamination (estimated on the basis of the contamination incidents detected in 1997 at Valognes railway terminal, on casks coming from French NPPs) has allowed to sort the different cask monitoring zones according to a "monitoring interest index" calculated as the relative probability of finding some residual contamination after the monitoring on that specific zone compared to the other zones, divided by the collective dose associated with the monitoring of that zone against contamination.

This index may be used as a "dosimetric cost - monitoring effectiveness" criterion that may allow to separate the zones for which a reinforced monitoring seems particularly interesting from those for which a less stringent monitoring could be envisaged.

This comparison has led to divide the cask into three groups: trunnions and trunnion bases, vertical and oblique parts of the front end, skirt side and seal face of the front part, for which the relative probability (compared to the other zones) of residual contamination reaches 80% while the monitoring of these zones represent only 36% of the collective dose associated with monitoring operations; vertical and oblique parts of the rear end, skirt side and seal face of the rear part, shock absorber at the rear end, with a relative probability of residual contamination of 20.5% and a contribution of 36% to the collective dose; horizontal parts of the front and rear ends, shock absorber at the front end, cooling fins, with a null probability of residual contamination in 1997 and a contribution to the collective dose that reaches 28% (11% for the cooling fins).

3.2.5 Possible protection actions

On the basis of the analysis of the contributions presented above, a set of possible protection actions has been identified and their potential dosimetric savings has been evaluated: reduction of waiting time/removal from cask (10.5%); discontinuation of double monitoring for the zones with no contamination detected in 1997 (10.5%).

The maximal potential dosimetric savings associated with the implementation of all these actions has thus been estimated to 21% of the collective dose resulting from the monitoring against contamination of the cask before shipment.

4 Conclusions

The estimate of the annual collective dose associated with the preparation and monitoring against contamination of the irradiated fuel casks before shipment from the French NPPs (1.3 man.Sv/y) is not negligible and corresponds broadly to the annual collective dose associated with the operation and maintenance of one average French reactor as well as a little less than 2% of the annual collective dose associated with the operation and maintenance of all French reactors.

Moreover, the preparation of the casks before shipment may represent almost the half part of the annual individual dose of the members of the general services involved at least once in the year in the preparation of a spent fuel shipment and may explain to a great extent the difference between the annual individual dose of the general services operators (involved in the preparation) and the radiation protection department operators (involved in the monitoring).

The operations of prevention, elimination and monitoring of the surface contamination of the irradiated fuel casks before shipment contribute significantly to the collective dose received by the operators during the operations of preparation and monitoring of the cask before shipment: 29% of the preparation collective dose and 90% of the monitoring collective dose, i.e. 42% of the total collective dosimetry.

Identified protection actions present potential dosimetric savings that are non negligible but limited: these potential savings are limited to 40 % of the preparation collective dosimetry, and 21% of the monitoring collective dosimetry, i.e. 36% of the total collective dosimetry.

As shown in Table 4, protection actions directly associated with the monitoring of the cask against contamination present much more limited potential savings (4% of the total collective dose) than protection actions associated with the preparation of the flask before shipment (31% of the total collective dose). However, these savings could reach more than 11% of the total collective dose if double monitoring was discontinued for every monitoring zone of the cask.

Table 4: Detailed potential dosimetric savings of proposed protection actions

Protection action	Dosimetric saving Preparation + monitoring collective dose
Liquid/vapour separator shielding	< 9% *
Elimination of special adhesives (before loading and transport)	8% *
Decontamination operations with full cavity	< 6% *
Desk protected from radiation	4% *
Remote display devices in the protected desk	2% *
Special adhesives (before transport) well suited	4%
Removal of the liquid/vapour separator from the draining orifice	3% *
Forms filling outside the fuel building	2%
Early exit of operators at the end of operation	2%
Reduction of waiting time / removal from cask	*2% **
Discontinuation of double monitoring for fins zone	*1% **
Discontinuation of double monitoring for caisson horizontal part	*1% **
Remote monitoring/emptying of the liquid/vapour separator	1%
Total preparation	**31%**
Total monitoring	***4%***
Total preparation + monitoring	**36%**

* Actions considered in the sum
Results associated with monitoring operations are presented under italics

Other protection actions, whose potential interest has not been (entirely) quantified, could be envisaged : choice of the best methods of protection of the cask external surface against contamination by the loading pond water; minimisation of operation mishaps and cask contamination events during the preparation before shipment; optimisation of each step of the monitoring procedure in terms of number/location of the smear tests and interest of a double control in order to minimise the collective dose spent to reach a same level of risk of residual contamination.

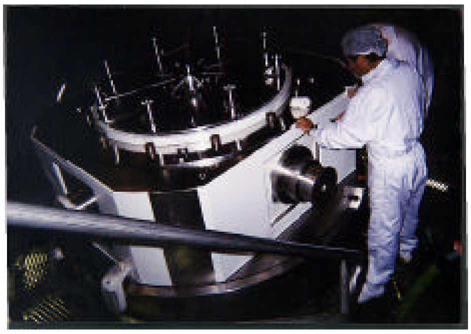
The implementation of these actions would require the organisation of past experience collection and analysis regarding: the respective interest of the different protection methods (vinyl cover, adhesives,…) in terms of both contamination prevention effectiveness and dosimetric impact on the preparation operations; the occurrence frequency and causes of operation mishaps and cask contamination events; the frequency and location of contamination events detected during the preparation of the cask as well as during its monitoring and double monitoring.

Finally, the studies described above have demonstrated the feasibility as well as the interest: of extensive analytical studies of the dosimetry - on a task per task basis –to identify the most potentially effective protection actions; of detailed statistical analysis of the dosimetry for the definition of dosimetric objectives (on the basis of expected average values) and the optimisation of the past experience collection (with the help of statistical "tolerance intervals" aiming to identify the good practices as well as the operation mishaps that may lead to an excessive dosimetry); in order to keep as low as reasonably achievable (ALARA) the doses associated with the spent fuel shipments from the French NPPs.

5 References

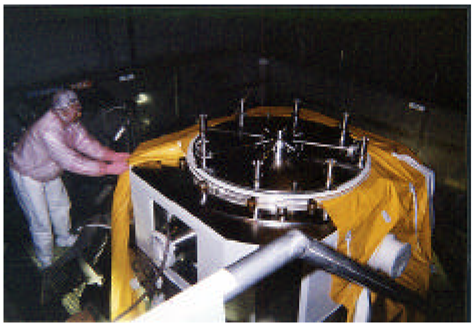
[1] Hughes J.S., Shaw R.B., Gelder R., Schwarz G., Fett H.J., François Y., Dellero N., Desnoyers B., Tchatalian B., Van Hienen J., Jansma R., Lefaure C., Degrange J.P. - Application of the ALARA principle to the decontamination of transport of irradiated fuel. Joint Report NRPB/GRS/TRANSNUCLEAIRE/NRG/CEPN, June 2001.

[2] Hughes J.S., Shaw R.B., Gelder R., Schwarz G., Fett H.J., François Y., Dellero N., Desnoyers B., Tchatalian B., Van Hienen J., Jansma R., Lefaure C., Degrange J.P. - Applying ALARA to the decontamination of irradiated Nuclear Fuel Containers. In: 'Packaging and Transportation of Radioactive Materials' (PATRAM '01), Proceedings of the 13th Conference, Chicago, USA, 3-7 September 2001.

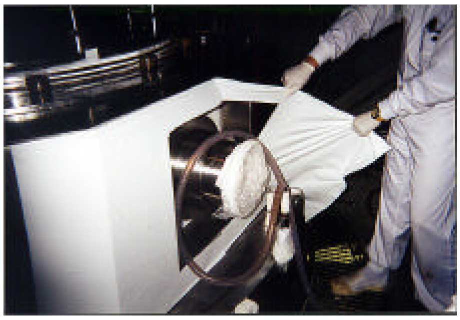


A: Adhesives fitting before loading

B: Cover fitting before loading



C: Cover unfitting after loading



D: Adhesives unfitting after loading

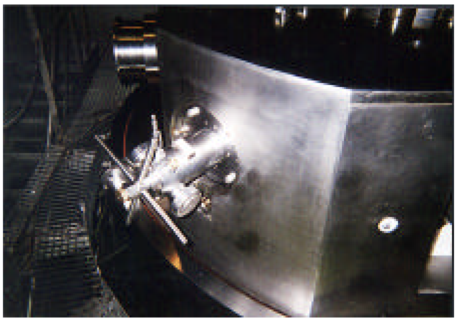
E: Decontamination of front part

F: Decontamination of rear part

G: Adhesives fitting before shipment

Figure 3: Operations of prevention and elimination of contamination

A: Emptying/draining/drying (control module)

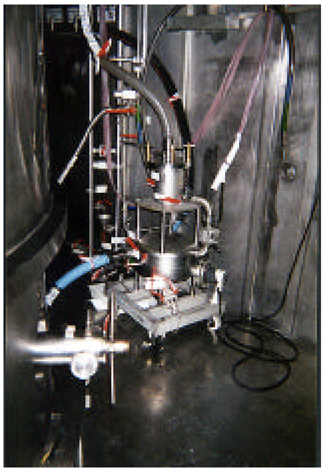


B: Emptying/draining/drying (A tool)

G: Handling (fuel building)

H: Handling (railway terminal)

C: Emptying/draining/drying (B tool)



D: Emptying/draining/drying (B tool, liquid/vapour separator)

E: Tightness monitoring

F: Other operations (tightening)

Figure 4: Flask preparation