SPENT FUEL CASK CONTAMINATION IN GERMANY: ANALYSIS, FINDINGS AND SOLUTIONS

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1 INTRODUCTION

The problem of contaminated spent fuel casks became internationally apparent end of April 1998. At this time the Director of the French Nuclear Installations Safety Directorate (DSIN) informed French Ministries and foreign authorities of countries like Germany and Switzerland that in the past a substantial fraction of spent fuel shipments when arriving at the railway terminal in Valognes operated by COGEMA had shown contamination events on casks and railcars. The International Transport Regulations impose limits of 4 Bq/cm² for β/γ-emitting and 0.4 Bq/cm² for α-emitting radionuclides for the non-fixed surface contamination on packages carrying radioactive material. According to the control measurements on spent fuel casks leaving nuclear power plants for the reprocessing plant at La Hague the non-fixed surface contamination was originally below the specified limits. But control measurements on casks and transport wagons upon arrival showed that in a larger percentage of cases the 4 Bq/cm² limit was exceeded and in some cases by large factors.

These findings initiated very intensive investigations and activities to solve this contamination problem in France, Germany, UK, Switzerland and other countries. In Germany this issue had a very high public and political weight for a long time and was broadly perceived as a major failure of nuclear industry.

It became quickly evident that the observed contamination events when transporting spent fuel casks revealed deficiencies in contamination prevention and control measures, in administrative procedures and in the information system among the companies involved and to the authorities.

2 ASSESSMENT OF THE CONTAMINATION PROBLEM

As one of the immediate consequences an assessments was initiated to clarify the situation, to understand the matter and the causes, to identify deficiencies and to propose remedial actions. The German Federal Authority of Railways (EBA) in its function as competent authority for rail transportation of radioactive material by German railway companies and the Federal Ministry of Environment, Nature Protection and Nuclear Safety (BMU) commissioned GRS to perform a detailed analysis. The systematic fact-finding activities and investigation of the causes by GRS included the following major aspects:

- Recording and processing of cases of contamination events found in the past for shipments of loaded transport casks from nuclear power plants to reprocessing plants or interim storage facilities and also for the shipment of empty casks to the nuclear power plants. This included the acquisition of the corresponding data and their entry and processing in a specially created database.

- Evaluation of the data stored in this database in order to obtain a clear representation of the facts and to track down systematic effects and correlations that are relevant for the clarification of the causes of the contamination.
- Analysis and comparison of measuring methods and the measuring scope applied for the contamination monitoring of casks and vehicles before the departure of the shipments, in transit and upon arrival at their destination.
- Thorough comparative analysis of the procedures applied in German nuclear power plants in connection with the loading, decontamination and checking for contamination of the casks as well as their evaluation with regard to correlations concerning the frequency and level of contamination found in the past. Important aspects in this connection were also the different types of casks, the associated handling processes, and measures to prevent contamination.
- Analogous examination of the measures on acceptance, unloading and returning of the transport casks at the foreign reprocessing plants as well as of the receiving inspection at the German interim storage facilities.

The essential information derived from the GRS assessment and data evaluation /GRS 98/ relating to the cases of contamination on consignments of irradiated fuel elements to the reprocessing plants in France and the United Kingdom and on return consignments of empty casks to German nuclear power stations is summarized in the following and illustrated graphically in Figures 1 and 2. The corresponding evaluations concerning empty consignments cover the period from 1988 to 1998 for which there exist sufficiently reliable data with regard to both reprocessors. The nuclear power plant operators mainly provided these data. As for loaded consignments, however, only a shortened period beginning in September 1995 was used for the representation of the fraction of contaminated consignments (Figure 1) because the complete data from BNFL was only available for this period. As to the level of contamination (Figure 2) of loaded transports, only shipments to COGEMA are represented, which meant that for this evaluation the longer period could be considered. For empty transports arriving at the nuclear power plants results are available for both reprocessing plants for the 10-year period.

Transports of empty casks arriving at German nuclear power plants from the two reprocessing plants showed local contamination events on cask surfaces at a frequency of 5% of the cases for COGEMA and of 3% for BNFL. For loaded casks contamination events were found in 6% of the transports when arriving in Valognes/La Hague and in 1% of the cases (one event) when checked at Sellafield. Checks for contamination are generally performed by taking a smear test over a surface area of 300 cm² and assuming that only 10% of the non-fixed surface contamination is removed by the smear. By referring to Figure 2 it can be concluded that all observed contamination events on empty casks when arriving at a nuclear power plant from BNFL were below 40 Bq/cm² and also in the case of casks coming from COGEMA contamination values were predominantly below 40 Bq/cm² and never exceeded 150 Bq/cm². It should be stated that measured contamination events below 40 Bq/cm² could very well have been artifacts in many cases because of the conservative assumption that the smear efficiency is only 10 %.

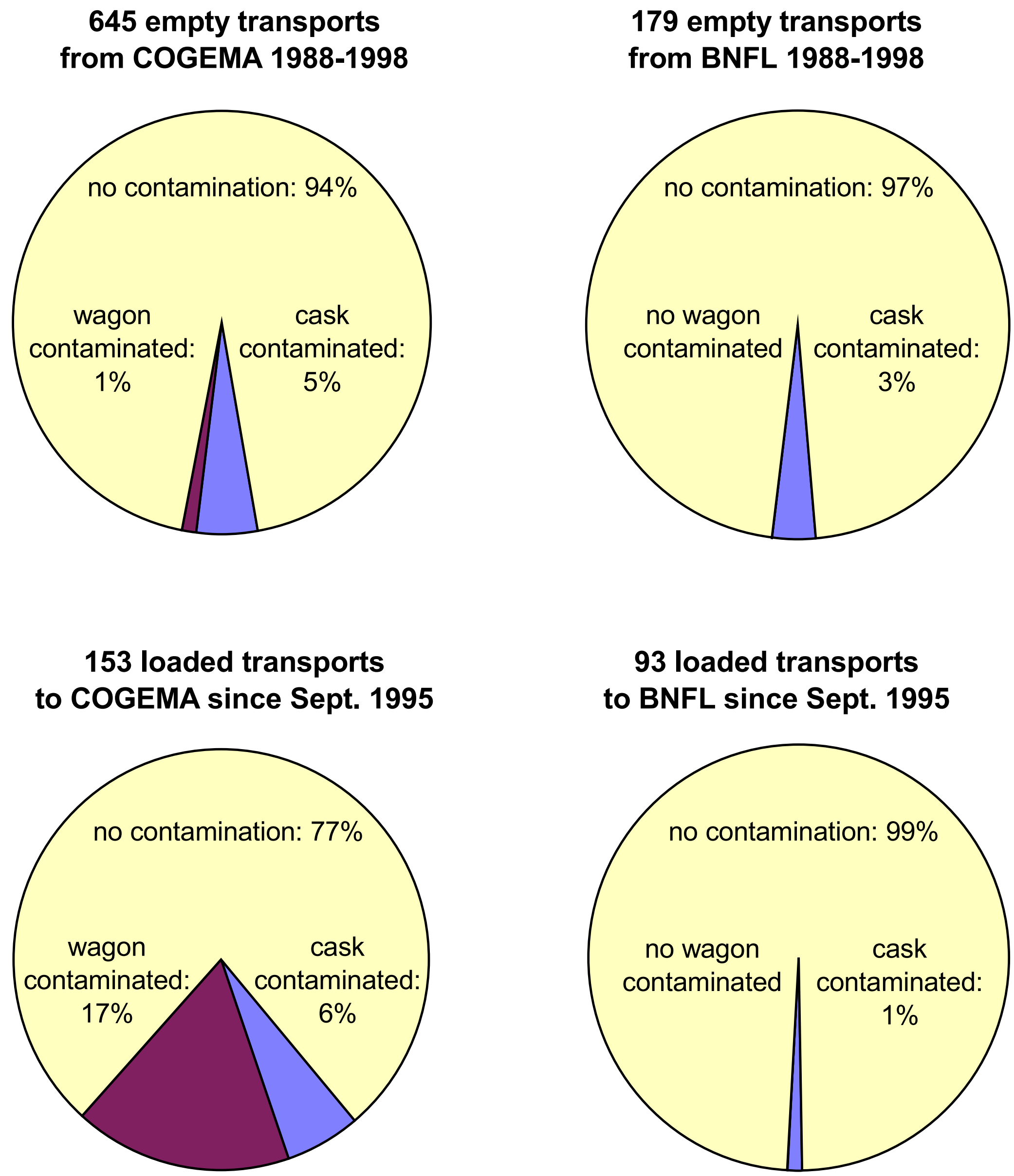

Figure 1: Fraction of contaminated consignments

As regards loaded casks the difference between the frequency of occurrence of contamination events of 6% for casks to COGEMA compared to 1% for BNFL is more pronounced. For loaded casks measured contamination levels were in tendency higher compared to empty casks but exceeded 150 Bq/cm² only in a small fraction of cases. Contamination values below about 150 Bq/cm² are compatible with the known „weeping“ phenomenon that the immersion of casks into contaminated pool water may initially lead to fixed contamination on cask surfaces which in the course of time, e.g. during the transport phase, is converted to non-fixed contamination and thereby becoming detectable by smear tests. Although, when comparing the two reprocessing plants, there were some differences in the number of smear tests and their locations on different types of casks that could influence the probability to detect cases where the 4 Bq/cm² limit was exceeded, it is judged that the observed differences are essentially real.

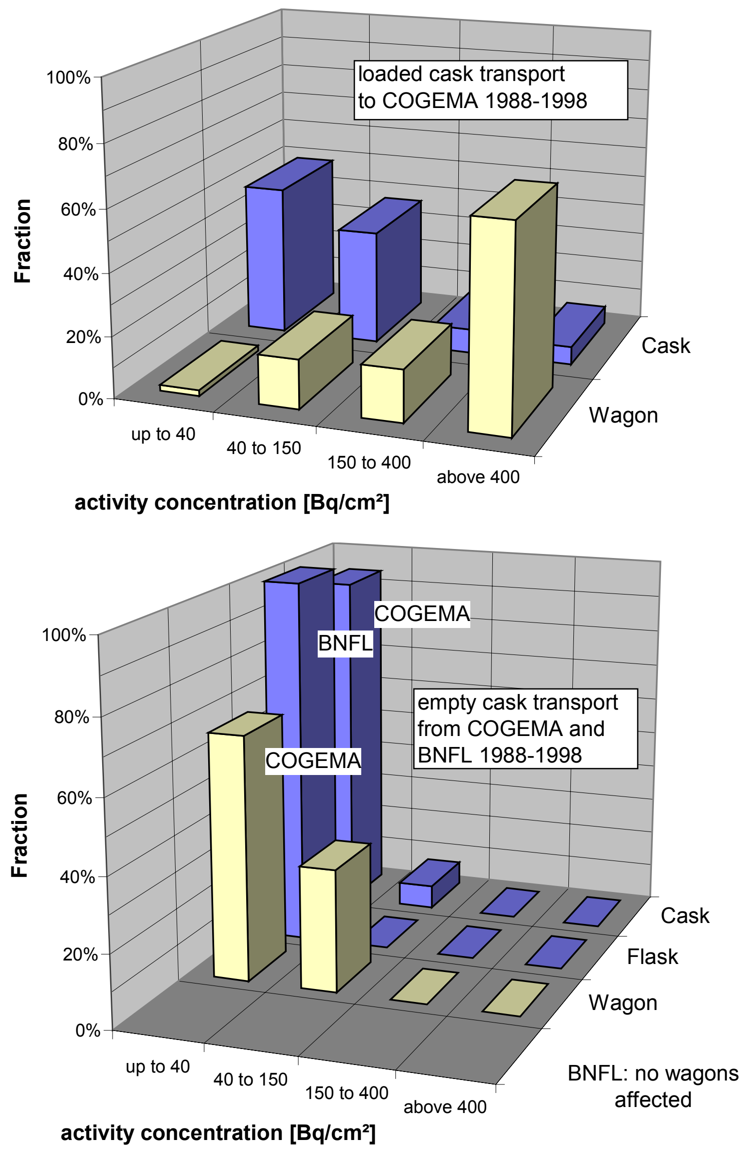

Figure 2: Level of contamination

Rail wagons arriving at Valognes were systematically checked after unloading of the cask carrying spent fuel elements. The low radiation field in the absence of the cask allowed contamination monitors to be applied as a means to directly identify locations with higher levels of contamination. The probability to detect any surface contamination exceeding the regulatory limits was therefore accordingly higher compared to other locations, e.g. power plants, where such direct measurement of vehicles were in general not performed with similar regularity and intensity. This should be born in mind when comparing the observed frequencies of contamination events between casks and wagons on the one side or between wagons at different location, e.g. the two reprocessing plants or between reprocessing plants and nuclear power stations.

3 ANALYSIS OF CAUSES AND DEFICIENCIES

By referring to Figure 1 it becomes evident that on a substantial fractions of wagons arriving at Valognes with loaded casks locations with excessive non-fixed contamination were found after unloading of the cask. For transports from Germany they were all localized in the inaccessible part of the wagon under the canopy and there mainly on the trip-tray underneath the cask. By comparing in Figure 2 the distribution of observed contamination levels on casks and on wagons for loaded transports to COGEMA it becomes evident that there are clear differences: Non-fixed contamination events on wagons have predominantly higher levels compared to casks. The explanation for this initially astonishing result is that in many cases the non-fixed contamination on the wagons is caused by single radioactive particles - so called hot spots - which have become detached from the cask after being loaded onto the wagon. There is enough evidence to support this interpretation. Such particles have been identified and in cases where their radionuclide composition was measured it is compatible with that of corrosion products which are found in the primary circuit of light water reactors and which become activated in the high radiation field of the core. In the literature these activated corrosion products are known as CRUD, they can either exist within the primary circuit as deposit, e.g. on fuel elements, or as particulate matter within the cooling water. Due to handling procedures when loading and unloading fuel elements and due to vibrations during transport operations such deposits can become detached from the fuel element surfaces. There is enough knowledge to approximately relate the activity of CRUD particles and their particle size.

This leads to the conclusion that single particles with an activity exceeding about 1000 Bq have an aerodynamic diameter above 100 μm. Accordingly, they are much weaker attached to surfaces than small particles and their settling velocity in air is so high (exceeding 30 cm/s) that they quickly deposit. Due to the weak attachment of large particles onto smooth surfaces it is unlikely that they are not removed by the cask cleaning procedures following loading or unloading of spent fuel elements. However, they may escape from being removed during the cleaning procedures by being deposited on covered surfaces or in gaps, cracks and crevices during cask immersion in the pool water. Due to vibrations during the shipment or other environmental effects these particles may become dislodged from these surfaces and will then very likely be found underneath the cask on the trip-tray of the railcar or the road vehicle.

Several further examinations of the past experience can yield valuable information to better understand the causes and to contribute to the solution of the contamination problem: Comparison of the frequency of contamination events and of the contamination levels for different light water nuclear power plants and for different cask designs. This is especially interesting if different types of casks were handled at the same NPP:

In the period from 1988 to end of April 1998 altogether 645 loaded spent fuel casks from 18 German nuclear power plants have arrived at the COGEMA terminal at Valognes. Two basic types of casks have been used: Casks of TN/NTL design with a cooling zone of cooling spikes such as TN 13/1, TN13/2, TN17/2, NTL 10 and casks with a cooling zone with cooling fins such as NTL 3, NTL 3M and NTL 11. The former are used for dry transports of spent fuel elements, i.e. no water in the cask cavity, the latter for wet transports with water filled cask cavity. 14 of the 18 nuclear power plants shipped exclusively casks with cooling spikes to La Hague, 2 shipped exclusively casks with cooling fins and 2 plants used both basic types of cask design.

Some nuclear power plants had no or only infrequently contamination events upon arrival at Valognes, some plants had intermediate results whereas on the other end some clearly exceeded a rate of 30% or even 40%. This is a strong indication that differences among the nuclear power plants in the protective procedures during loading of the casks, the following cleaning process and associated cask handling and control and in the experience and cleanliness of the operations played a major role. No clear differences are seen between casks with cooling spikes on the one side and casks with cooling fins on the other. Casks with cooling spikes are represented throughout the spectrum of low, medium and high contamination event frequency as are casks with cooling fins. When comparing the performance of these different cask designs for the two nuclear power plants which used both types there is no difference with respect to the frequency of contamination events for the TN cask with cooling spikes and the NTL 11 casks with cooling fins. When comparing the overall performance of both cask types on average 22% of 452 shipments of casks with cooling spikes and 32 % of 151 shipments of NTL 11 casks with cooling fins had contamination events. As regards the frequency of contamination events on casks and/or railcars there is clearly no indication that casks with cooling spikes performed worse than casks with cooling fins which are in principle easier to decontaminate or to control should the protective skirt of the cooling zone have failed during the loading process or should contamination have been transferred in the course of cask handling procedures.

There is still the additional possibility that contamination events occurring for the two different cask designs show differences with respect to the level of contamination on casks and wagons or with respect to contamination originating from “hot spots”. When comparing the distributions of contamination levels for casks with cooling spikes and for the NTL 11 with cooling fins no clear difference is found between both cask designs in the contamination levels on the cask surfaces and on the railcars. Neither concerning contamination distributed over a surface area nor contamination originating from “hot spots” there are systematic differences between both cask designs.

4 REMEDIAL ACTIONS

Up to May 1998 the majority of spent fuel transports from German light water reactors went to the reprocessing plants of COGEMA in France and BNFL in UK. Considering the last 10 years period from 1988 up to May 1998 in total 645 casks were transported to COGEMA and 179 to BNFL and altogether only 11 to the interim storage facilities in Ahaus and Gorleben. This is equivalent to an average annual shipping volume of 80 spent fuel casks. Following the interruption of these shipments in May 1998 ten criteria had been defined by the BMU and associated measures to be taken had been issued in a “Catalogue of measures for the resumption of spent fuel ... shipments” in which the requirements to be implemented for the resumption of the interrupted transports were specified. These documents required, among others, a resumption of transports in 3 phases. Phase I is an initial cold handling in each NPP of a certain type of spent fuel cask without loading but employing all other protection, cleaning and controlling measures. During Phase II a number of 3 to 5 transports are conducted with an enhanced program of controlling measurements, the transition to routine transports of Phase III requires that on the basis of the experience from the previous phases it can be expected that further transports will very likely be in accordance with regulatory requirements.

In addition, the concept of the "closed transport cycle" was introduced. The utilities had to document in detail how the casks and vehicles are handled, cleaned and controlled and how contamination transfer is avoided at the various stations such as nuclear power plants, reloading stations and reprocessing plants or interim storage facilities in order to prevent in the future contamination problems with high reliability. On this basis the utilities had submitted detailed documents which separately refer to inner German transports of spent fuel to interim storage facilities and to the transport of spent fuel from German NPP to the reprocessing plants of COGEMA and BNFL. In these documents all contamination relevant procedures and measures which casks and vehicles experience in the course of the loading process at the plant, during transport operations and upon arrival at the destination are described and the fulfilment of the requirements of the Transport Regulations, of the additional BMU criteria and of the associated catalogue of measures demonstrated. Where appropriate, the submitted documents had been prepared in close collaboration with COGEMA and BNFL. These documents have been evaluated by GRS in collaboration with Oeko-Institute and recommendations and remarks have been formulated which were then implemented.

As an illustration, for transports of spent fuel to reprocessing essential changes compared to the situation before the "crisis" are highlighted here concerning protective measures, cleaning activities, control measures and the documentation and reporting system:

- When casks are immersed into the pool to load fuel elements the protection against contaminated water and "hot particles" is upgraded. In the case of casks of TN design the cooling spike zone used to be protected during loading at the nuclear power plant and in La Hague - if unloaded under water - by a metallic contamination skirt. As an additional protection measure during loading and unloading under water, a further contamination protection device is now applied which has the following three objectives: the surface area of the cask that is protected from contact with pond water is considerably enlarged; the cooling spike zone is further protected by a second barrier to the pond water through the additional protection of the two seals of the metallic skirt; the proper functioning of this protective measure can be checked. As far as these casks are unloaded under water in La Hague also in this case an additional barrier provided by a plastic skirt surrounding the metallic skirt and large parts of the cask surface is required for German shipments. This measure is not applied at COGEMA for transports from French EdF power plants and also not for unloading of casks under water at BNFL.
- Protective measures to avoid contamination of cask surfaces during loading and unloading have been reviewed and upgraded and also the consecutive cleaning procedures. Emphasis is placed on avoiding any cross-contamination from potentially contaminated parts to clean parts of the cask. This could be the case in the course of the cleaning process or when protective devices are removed from the cask.
- For the entire transport cycle consisting of the shipment of the empty cask to the nuclear power plant, its loading with fuel elements, the transport of the loaded cask to the respective reprocessing plant, and its unloading and renewed preparation for shipment provisions to avoid contamination and associated controls are implemented. Special attention is given to avoid any contamination transfer from working areas and handling equipment by appropriate control measures.
- The phase concept for the resumption of transports requires that following Phase I (cold handling) in Phase II which consists of the first 3 to 5 shipments of a certain cask type from a specific NPP these are accompanied by an extended program of measures and contamination

monitoring. The enhanced program of control measurements across the entire transport cycle requires correspondingly comprehensive documentation during this phase.

- The examination of earlier practices in connection with shipments to and from nuclear power plants and reprocessing plants showed as necessary improved measures in particular a consistent standardisation of control measurements and their recording in the transport documentation under inclusion of the different reloading stations where casks are transferred from one transport means to another. There was no closed flow of information among those involved in the shipments, and the regulatory authorities responsible in Germany were not informed reliably. As a consequence a closely co-ordinated and verifiable information and reporting system has been developed.
- Several further actions include improvements in the organisation of spent fuel transports, the introduction of a "nuclear transport responsible person" in the NPP's, training of personnel and information exchange among the NPP's, reprocessors and transport organisations as well as third party inspection of selected operations and of contamination control measurements.

5 CONCLUSIONS

The implementation of all requirements as specified in the BMU criteria for the safe transport of spent fuel and the associated catalogue of measures for the resumption of spent fuel shipments turned out to be a very time consuming process despite great efforts from the side of the German utilities and the two reprocessing plants and also of GRS and Oeko-Institute who were commissioned to evaluate the associated very detailed documents e.g. /LAN 99/. All technical, organizational and administrative measures were directed at avoiding with high reliability any contamination events following resumption of the shipments. In principle, the various improvements which have been adopted in other countries following the “contamination crisis” are of similar but not in all cases of identical nature as the approach adopted in Germany. This reflects possible variances in judgement and balancing of competing aspects to cope with the contamination problem.

Transport of spent fuel casks to foreign reprocessing plants have resumed in Germany after almost a three-year interruption in April 2001. Up to the middle of August all shipments of in total 31 fuel casks to either COGEMA or BNFL were without any contamination event.

6 REFERENCES

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