SAFETY REQUIREMENTS FOR WASTE PACKAGES,

THE BASIS FOR ACCEPTANCE CRITERIA OF THE KONRAD REPOSITORY

W. Wurtinger, D. Gruendler
Gesellschaft fuer Reaktorsicherheit (GRS) mbH
5000 Koeln, Federal Republic of Germany

ABSTRACT

Safety related requirements for the acceptance of waste packages due for final disposal in the repository planned for the Federal Republic of Germany in the KONRAD iron ore mine were derived from site-specific safety analyses.

These requirements which will become part of future acceptance requirements were grouped as basic requirements which are independent of the activity inventory and activity inventory dependent requirements. With respect to activity inventories, two waste classes were defined. Waste forms within waste class I have to meet already relatively high standards and are further differentiated into six waste form groups. Waste forms of a higher activity inventory are correlated to waste class II, where the packagings have to be designed to resist incidents.

The practical application of the requirements to several waste examples has been proven.

INTRODUCTION

In the Federal Republic of Germany it is planned to dispose of radioactive wastes with negligible heat production in the former iron ore mine KONRAD. The planning stage for this repository in a deep geological formation has been completed to the extent that the licensing procedure was initiated by the Physikalisch Technische-Bundesanstalt (PTB), which is responsible for the final disposal of radioactive wastes in the Federal Republic of Germany.

An essential part of the planning stage was specifying the safety related requirements for the radioactive waste packages due for final disposal. These are based on a site specific safety analysis (1) and will become part of the future acceptance requirements and are, therefore, of particular interest to the waste producer. In accordance with the acceptance requirements, the waste producer will have to condition their wastes if they want to ensure that their wastes will be accepted for disposal in the repository.

The following describes the type and extent of the safety related requirements. It will be shown on which safety aspects these requirements are based and how they are derived. Furthermore, several examples will be discussed to show by which kind of conditioning or packaging these requirements can be met.

The corresponding study was carried out under contract for the Physikalisch-Technische Bundesanstalt (PTB).

CLASSIFICATION OF SAFETY RELATED REQUIREMENTS

The safety related requirements for waste packages due for disposal in the KONRAD repository, discussed in this paper, are the result of the analyses of the radiological safety during specified normal operation and during incident. Further requirements, e.g., the activity limitation due to the limitation of heat production in the host rock, are not discussed.

The requirements for the waste packages result, essentially, from the following safety objectives applying to the operational phase of the repository:

- Avoiding operational interruptions during the handling of waste packages,
- an as low as possible radiation exposure of the operating personnel during handling of the waste pakages,
- an as low as possible activity release due to leackages of the waste packages,
- prevention of incidents,
- limiting the activity release from waste packages due to an incident.

Strictly operational concerns lead to the initial requirement for standardizing the waste packagings with regard to size and shape. It is for this reason that wastes packed in drums will not be accepted for deposit in KONRAD: these wastes have to be packaged in containers (2, 3). The maximum allowed dimensions and weights are specified on the basis of the lifting and transportation equipment available in the repository.

This standardization of the waste packagings furthermore, contributes to minimizing the radiation exposure of the operating personnel from direct radiation.

The standardized containers allowed for packaging radioactive wastes for the KONRAD repository are listed in Table I according to their shape and exterior dimensions (4).

Additional requirements regarding the design of the containers and the conditioning of the wastes result from radiological considerations. Thus, during normal operation as well as in the case of incidents specified dose limit values may not be exceeded. Therefore, as a first step within the framework of safety analyses, a large number of different waste packages were analyzed with regard to the release of

TABLE I

Standardized packagings for the disposal of radioactive waste in the Konrad mine (from Ref. 4)

No.	Designation	External dimensions length/dia. (mm)	width (mm)	height (mm)	Gross volume (m^3)	Mass of waste package (Mg)
	Concrete packaging					
1	Type I[4]	∅1060	–	1370[1]	1.2	ca. 3...4
2	Type II[4]	∅1060	–	1510[2]	1.4	ca. 3...4
3	Type III[4]	∅1400	–	2000	3.1	ca. 10...13
	Cast-material packaging					
4	Type I[4]	∅ 900	–	1150	0.7	ca. 3...6
5	Type II[4]	∅1060	–	1500[3]	1.3 (1.2)	ca. 7...12
6	Type III[4]	∅1000	–	1240	1.0	ca. 3...6
	Boxes					
7	Type I[5]	1600	1700	1450[6]	3.8	≦ 20.0
8	Type II[5]	1600	1700	1700	4.6	≦ 20.0
9	Type III[5]	3000	1700	1700	8.7	≦ 20.0
10	Type IV[5]	3000	1700	1450[6]	7.4	≦ 20.0
11	Type V[5]	3200	2000	1700	10.9	≦ 20.0
12	Type VI[5]	1600	2000	1700	5.4	≦ 20.0

[1]) height 1370 mm + lug 90 mm = 1460 mm
[2]) height 1510 mm + lug 90 mm = 1600 mm
[3]) and height of 1370 mm, KfK type (KfK = Karlsruhe Nuclear Research Center)
[4]) supplied on pallet
[5]) materials are e.g. steel plate, cast iron, reinforced concrete
[6]) stacking height 1400 mm

TABLE II

Classification of the Safety Requirements of Radioactive Waste Packages

Requirement	Classification	Objective
independent of activity	basic requirements	design of the waste packages - for handling and - to avoid operational interruptions and incidents
dependent on activity	waste class I	packaging resistant to operational loads incident resistant waste form
	waste class II	incident resistant packaging

radiocative materials during normal operation and in the case of incidents. The information regarding these waste packages result from a data survey of the different waste producers that was carried out by PTB (5). These data are a representative cross-section of the different types of waste packages intended for deposit in the KONRAD repository.

This analysis was carried out with the objective in mind of deriving safety related requirements. It soon became evident that it would be sensible to separate the requirements into two groups. The first group encompasses the requirements that waste form and packaging have to fulfill independent of the activity inventory of the waste product. The second group encompasses the requirements that concern the activity inventory and its nuclide specific composition. As shown in Table II, the first group encompasses the so-called basic requirements whereas the second group is further subdivided into waste class I and waste class II.

The basic requirements pertain to the capability of handling the waste packages in the repository and the prevention of operational interruptions and incidents. The subdivision of the second group of requirements into two waste classes is based on the fact that with low activity inventories the release of radioactivity in the case of incidents is limited due to the release-reducing properties of the waste form. Thus, an incident-resistant design of the packaging is not required for waste class I. Only as the activity inventory is increased to a level that an activity release due to incidents is not anymore sufficiently counteracted by the release-resistant properties of, e.g., the fixation of the waste material in a cement matrix, then (waste class II) the packaging must be designed to be incident resistant.

The derivation and quantification of these design limits shall, in the following, be shown for the incident analysis which led to the design limit between waste classes I and II.

DERIVATION AND QUANTIFICATION OF SAFETY RELEVANT REQUIREMENTS

The result of the incident analysis for the KONRAD repository was that, regarding the waste packages, three design basis incidents have to be considered. These incidents are

- the drop of a waste package from a height of 3 m during unloading upon delivery in the aboveground reloading facility,
- the drop of a waste package from a height of 5 m in the underground storage chamber and
- fire of the loaded transport equipment underground at a temperature of 800 °C for a fire duration of 1 h.

In all cases it was analysed what loadings the individual waste package was subjected to, to what extent radioactive materials would be released from the waste form and package into the facility, to what extent a subsequent release to the environment would occur from the facility and what the maximum radiation exposure of persons in the vicinity of the facility would be.

Waste Class I

In the analysis it was assumed that, in the case of waste packages that meet the requirements of waste class I, the packaging will be destroyed by the incident load or will become so porous that it will no longer function as barrier against activity release. Thus, in the case of mechanical loading a complete destruction of the packaging was assumed, i.e., it was considered as being nonexistent. In the case of the incident fire on the other hand, the packaging was considered as existent, however, without any barrier function against activity release. Its only remaining effect would be to reduce the access of oxygen to such an extent that only pyrolysis could occur.

The result is that the packaging of waste class I has to meet only few safety related requirements. The basic requirements for the packagings of this class are, essentially,

- stackability,
- corrosion resistance,

and that the packaging is free of mechanical and corrosive damages upon delivery at the repository. Aside from these basic requirements, the only other requirement is that the packaging keeps its integrity upon a drop from a height of 0.8 m onto an unyielding surface. If the packaging meets these requirements it is also ensured that, in case of the incident fire, access of oxygen is limited to the required extent.

Thus, in waste class I the limitation of activity release under incident loadings is predominantly achieved by meeting requirements regarding the chemical and physical properties of the waste form and by a corresponding limitation of the activity inventory.

In order to derive these requirements the properties of the different waste forms that influence activity release were analysed. As an example, the experiments that determined the content of fine particles due to mechanical loading of wastes fixed in a cement matrix were systematically evaluated, also, with regard to activity release (6). An example of this evaluation is shown in Fig. 1.

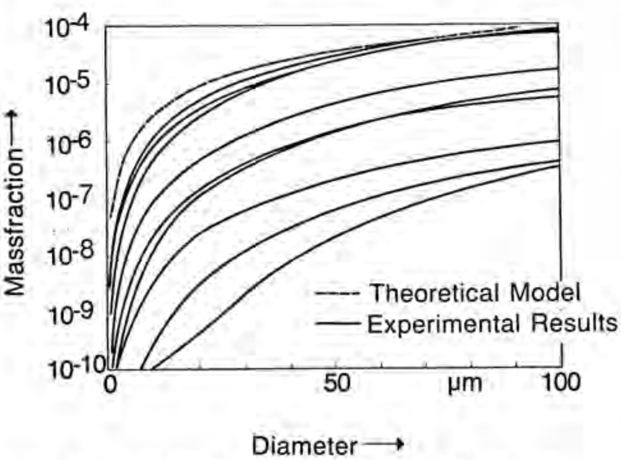

Fig. 1. Size distribution after mechanical impact on cemented products

Figure 1 shows the experimentally determined particle size distribution which results from the mechanical loading of different cement matrices with an energy impact of 0.05 J/g. For determining the release of activity, it was assumed, firstly, that particles up to a diameter of 100 μm are able to be airborne and, secondly, that the upper envelope shown in Fig. 1 is a conservative estimate of the portion of released masses.

In order to be able to cover the many different waste forms by comparable release analyses of the mechanical and thermal load case, several waste form groups had to be established. Analyses showed that the different properties relevant to activity release could be properly differentiated by introducing six waste form groups. Table III shows the percentage of released materials determined for these six waste form groups both for the mechanical load case (3 m drop) and for the thermal load case (fire).

TABLE III

Waste Forms Groups with Activity Release Fractions caused by Incidents

No.	Waste Form Groups	Drop [%]	Fire [%]
01	bitumen and plastics	0,3	50
02	solid matter	0,3	1
03	metallic solid matter	-	0,4
04	compacted waste	0,0046	0,16
05	cemented/concrete waste	0,0007	0,05
06	solidified concentrates	0,0007	0,05

From the different parameter values associated with the determination of the percentage of released materials, different requirements result with regard to the condition of the waste form depending on which of the waste form groups it is correlated to. This means that, the lower the value of percentage of release is as specified in Table III for a particular waste form group, the stricter are the requirements for the condition of the waste form. On the other hand, those waste form groups for which a small percentage of released material was determined are allowed to contain a larger activity inventory. This gradation in the requirement profile of the six waste form groups is shown in Table IV.

The first column of Table IV lists the number of the waste form group as per Table III. The second column lists, in key-words, the required characteristics of the individual groups. The last column shows the maximum allowed activity inventory for the individual waste form group.

The allowable limit values for the activity inventory were calculated on the basis of individual nuclides. Starting with the waste-form-group specific activity release values calculated for the individual incidents (see Table III), the activity inventory allowed with respect to the limit values regarding body dose during incidents (see Ref. 7: Sec. 28 para. 3) was calculated separately for each nuclide. The limit values in Table V are the results of this calculation for the single nuclide Co-60. In reality, the activity inventory consists of a nuclide mixture whose allowable limit is then calculated with a summation equation from the individual values. A list of these limit values for the individual nuclides depending on both the individual waste form group and waste class are a part of the acceptance criteria.

TABLE IV

Properties to be met by the Waste Forms in Waste Class I

No.	Properties *)	Max. Activity Inventory (Co 60 / Bq)
01	--	< 4.9 10^{10}
02	• combustibility - limitation of the percentage of combustible materials (T_S < 300 °C) - fixation of combustible materials (T_S < 300 °C)	< 2.4 10^{12}
03	• purity of materials - metals - absorber materials	< 6.2 10^{12}
04	• solidity - solid compacted	< 1.6 10^{13}
05	• solidity - concrete fixation - waste distribution - strength	< 4.9 10^{13}
06	• combustibility and solidity - solid substance - non combustible	< 4.9 10^{13}

*) required in addition to the basic requirements

TABLE V

Basic Requirements to be met by the Waste Forms

Protection Objectives	Basic Requirements
avoidance of incidents	
• fire	• not self ignitable
• explosion	• non-explosive material • no gas ampouls or bottles
• criticality	• limitation of fissionable materials
avoidance of operational interruptions	• solid or solidified • no free liquids • non-rotting or fermentable

It is seen from Table IV that a waste package in waste class I whose waste form does not meet any of the listed product requirements presented in the Table has to be correlated to the waste form group 01. This group has the most restrictive limit value for the activity inventory. Otherwise, the waste packages in this group need to meet merely the basic requirements already mentioned above. These basic requirements, as listed in Table V, have to be met by all waste packages intended for deposit in the KONRAD repository.

If, by conditioning or sorting, the waste forms meet the individual requirements of one of the other waste form groups regarding combustibility, purity of material or solidity, then the activity inventory may be increased accordingly.

Waste Class II

Waste packages with higher activity inventories than allowed for waste class I can be correlated to waste class II if the higher limit values allowed for this class are not exceeded.

The higher activity inventories of waste class II result from the fact that in this class the packaging is required to be incident resistant. The safety related requirements regarding these packagings were derived from an activity release analysis similar to that of the waste forms.

In case of the drop of the waste package with solid or solidified waste forms (which, in accordance with the basic requirements of Table V, is the only form allowed), an activity release can be safely limited by the requirement for a maximum allowed leakage rate of the packaging before and after the drop. These limit values of leakage rates specified for the packagings in waste class II are presented in Table VI.

In case of the incident fire, the allowable design limits were determined from a computer modelling of the packagings. An example of these calculations is presented in Fig. 2 showing the calculated mean temperature as a function of time at the inner wall of a cast iron container of type II with its outer wall being subjected to the temperature course expected for the incident (dashed curve in Fig. 2).

For a waste form meeting only the low requirements with respect to thermal stability of waste form group 01, the pressure buildup in the container, the activity release to the gas plenum of the container and the resulting integral activity leakage from the container was calculated for the complete heat-up phase and a given initial leakage rate of the container. The requirement that the integral activity leakage rate must be limited to 1 mole of the overall volume of the gas plenum leads to the analytically verified requirement regarding the leak-tightness of the container under thermal loading as shown in Table VI. The maximum allowed activity limit values that result from these design limits are shown in the second column of Table VI for several nuclides typical of nuclear power plant wastes.

TABLE VI

Requirements to be met for Packagings of Waste Class II

Packaging	Max. Activity Inventory	
	Radionuclide	Bq
• tightness after mechanical impact	J 129	4,4 10^{11}
- leakage rate $\leq 10^{-4}$ Pam^3/s after 5 m-drop	Sr 90	3,1 10^{13}
	Cs 137	6,7 10^{14}
• tightness *during* and after thermal impact (800 °C for 1 h)	Co 60	8,1 10^{14}
- leakage rate before fire $\leq 10^{-5}$ Pam^3/s		
- leakage rate after fire $\leq 10^{-4}$ Pam^3/s		
- integral leakage of the package during fire $\leq$ 1 mole of the gas plenum		
or		
• thermal resistance of wall $\geq$ 0,1 m^2 K/W		

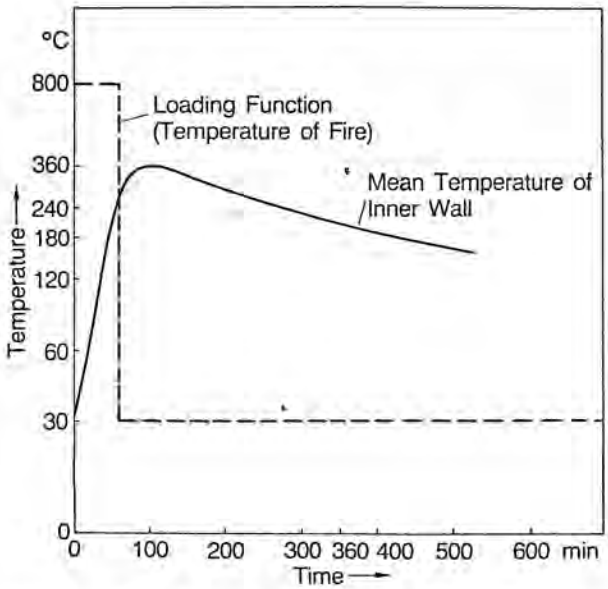

Fig. 2. Calculated mean temperature over the inner wall of a cast iron container during fire

The activity release from the waste package during fire can also be kept within the allowed limits by designing the packaging against heat-up of the content. This alternative to the requirement of leak-tightness upon thermal loading is achieved by designing the packaging with a heat conductivity resistance higher than the value cited in Table VI of 0.1 m^2K/W.

DISCUSSION OF EXAMPLES

Waste Class I

The relatively minor requirements that apply to the packaging of waste packages in waste class I are practically already met by fulfilling the design criteria for the radioactive waste packages imposed with regard to transportation and intermediate storage. This is especially important regarding the waste packages currently in intermediate storage which, without further reconditioning, are intended for final deposit in the KONRAD repository.

Examples for such waste packages are radioactive wastes in drums with a lost concrete shielding or wastes in cast-iron containers. These are the predominant types of conditioned wastes currently in the intermediate storages of nuclear power plants. The contained wastes stem, essentially, from the coolant purification and the waste water cleaning facility and contain, e.g., evaporator condensates and ion exchange resins. A survey of these wastes from nuclear power plants with regard the activity inventory and whether a correlation to waste class I is possible has shown that practically only the very highly radioactive ion exchange resins and the wastes from the reactor core have to be treated as waste class II (8).

Typical wastes of waste class I are the contaminated solids that stem from regular reactor operation. These wastes that, formerly, were dominantly compacted as so-called pellets or were incinerated and then packed in drums will, in the future, have to be packed in containers for final deposit in KONRAD. The conditioned wastes packed in drums, as they are currently used in the intermediate storages, will have to be put into the container type V (see Table I) and filled with cement. Already executed drop-tests at the manufacturers of these containers indicate that such a container with an overall weight of up to 20 t will meet the requirements for packagings in waste class I (0.8 m drop).

Waste Class II

A complete survey of which of the currently available containers of the types listed in Table I will meet the requirements of waste class II, is intended to be carried out in the course of the advancing licensing procedure for the KONRAD repository. Current results indicate that the cast-*iron* containers presently in use meet the requirements with regard to both the mechanical as well as thermal loading. This assumption is founded on a number of fire and drop tests that were already carried out.

CONCLUSION

The safety requirements for radioactive waste packages that were developed for the KONRAD repository will become an essential part of the future acceptance requirements. The requirements were structured such that the waste producer has the largest possible range in choosing a conditioning procedure that is adequate with regard to final disposal of the waste. He can choose between different combinations of requirements by properly correlating waste classes and waste form groups. These combinations all ensure the same safety and give him the freedom of choosing the procedure best suited for his particular wastes.

REFERENCES

1. "Sicherheitskriterien fuer die Endlagerung radioaktiver Abfaelle in einem Bergwerk", Bundesanzeiger 35, No. 2 (1983) 45-46, Federal Ministry of the Interior (Ed.), Bonn, FRG

2. P. Brennecke, "A Survey of the Radioactive Wastes in the Federal Republic of Germany", Finnish-German Seminar on Nuclear Waste Management, Otaniemi, Espoo, Finnland, Sept. 23-25, 1986

3. L.G. Sütterlin, "Low Level Nuclear Waste Management and Disposal", The 1986 Washington Conference on Low Level Nuclear Waste Disposal and Cleanup, CEEM, Alexandria, Virginia, May 22-23, 1986

4. "Long-Term Storage and Disposal of Radioactive Waste", Division SE, Annual Report 1985, Physikalisch-Technische Bundesanstalt, Braunschweig (1986), FRG

5. P. Brennecke, E. Warnecke, "Waste Acceptance Requirements: Procedure and Basic Data", Proc. of the International Seminar on Radioactive Waste Products, Nuclear Research Establishment Jülich, 10-13 June 1985, Jül-Conf-54, FRG

6. D. Gründler, "Accidental Release of Radioactivity from Waste Packages in a Final Waste Repository", Proc. Waste Management '85, Tucson, Arizona, March 24-28 1986

7. "Verordnung über den Schutz vor Schäden durch ionisierende Strahlen", Bundesgesetzblatt, Vol. 1976, Part 1, No. 125, Bundesanzeiger Verlagsgesellschaft Bonn, Federal Ministry of the Interior (Ed.), Bonn (1976), FRG

8. D. Gründler and W. Wurtinger, "Specification of Safety Requirements on Waste Packages with Respect to Practicable Quality Control Measures", Proc. Waste Management '87, Tucson, Arizona, March 1-5, 1987