Development of a Monolith-Type Package for Transport and Storage of Radioactive Steel with Particular Respect to Volume Reduction

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1. INTRODUCTION

NUCLEAR WASTE METAL RECYCLING/REUSE

The Community's technological research aims at promoting the setting up of a regulatory framework to protect humans and environment within which industrial activities can develop. An example where particular efforts have been undertaken is the reuse/recycling of nuclear metallic waste. One of the most promising (particularly in Germany) recycling routes is the use of low-level radioactive steel to produce items for the nuclear industry, eg, packages for transport and/or storage of nuclear waste, which would save costly storage volume and, at the same time, the consumption of raw steel. This route is strongly considered for the possible German Konrad disposal site where packages of a maximum total weight of 20 Mg may be stored. Before casting large packages, specific knowledge was needed with respect to problems occurring in the presence of radionuclides, as well as knowledge on technical characteristics of the cast product.

MELTING OF RADIOACTIVELY CONTAMINATED STEEL

Melting of low-level radioactive steel has essentially been sponsored by the CEC during the last ten years in the framework of research shared-cost contracts, mainly with British Steel Corporation and Siempelkamp Gießerei. Whereas British Steel researched the possibility of retaining cesium in the acid slag by trials in industrial furnaces, Siempelkamp Gießerei has developed a melting facility authorised to process nuclear scrap with activity levels up to 74 Bq/g in a 20 Mg capacity induction furnace. After having molten 1500 Mg of this scrap, a single-purpose plant of 3.2 Mg capacity was built, authorized to melt scrap up to 200 Bq/g. Various series of specific melting tests have been performed from 1982 until now and over 5000 Mg of low radioactive steel have been processed by melting, the results of which have been or will be published by the CEC. A recent contract concluded with the CEA-UDIN at Marcoule aims at the melting of larger steel components from the primary circuit of the French G2/G3 GCRs in a 15 Mg arc furnace with respect to waste volume reduction and/or free release.

DEVELOPMENT OF TRANSPORT AND STORAGE PACKAGES

In the framework of the 1984-88 EC research programme, the development, qualification and testing of a Konrad VI type container (1.6 x 2 x 1.7 m) has been carried out by Siempelkamp Giesserei. About 20% (4.22 Mg) of steel < 10 Bq/g is reused for each container. Results of these developments were presented at PATRAM'89 in Davos, Switzerland.

In 1986 investigations started within the framework of a research contract concluded with KRB Gundremmingen, Siempelkamp and GNS to develop a compact Konrad-type steel package, capable of storing steel up to 500 Bq/g.

This paper mainly relates to these developments and shows its application to the KRB-A pilot dismantling project.

2. KRB-A DISMANTLING WITH PARTICULAR RESPECT TO WASTE VOLUME REDUCTION

Within the framework of a shared-cost research contract between the CEC and KGB-Gundremmingen concluded in 1986, investigation started to identify the most dose- and cost-effective route to dispose of large steel components of the KRB-A BWR (250 MWe) under decommissioning since 1980, with particular respect to waste volume reduction and therefore saving costly storage/disposal volume.

Approximately 50% of the steel was decontaminated for unrestricted release. The other half (1,500 metric tons of steel) - mainly pipes and valves with small diameters, *i.e.*, with complicated geometry - was handed over to Siempelkamp Gießerei to produce cast iron components for the nuclear industry (already presented at Patram'89).

Since 1989, the decommissioning activities have mainly been related to the primary water-affected steel components in the reactor building with a total activity of about 1.5 x 10^{12} Bq (approx. 40 Ci) and contamination values of 1,000 to 40,000 Bq/cm^2.

2.1. WAYS TO REDUCE NUCLEAR STEEL WASTE

In Germany for instance, more than 5,000 DEM (2,500 ECU) per m^3 are needed for intermediate storage of low- or medium-level waste. The estimated costs for a subsequent final disposal (possibly in the Konrad mine > 1997) would be at least the double. Therefore, minimization of the waste volume is a strong challenge, and it is worth developing appropriate techniques.

Authority requirements
The German atomic law "Atomgesetz" prescribes the preference for recycling of dismantled material instead of disposing of it as radioactive waste - as long as technically and economically achievable. Presently, rather low activity limits for free release of steel are valid (0.5 Bq/cm^2 and 0.1 Bq/g). Steel with residual specific activities > 1 Bq/g can be treated by melting for restricted reuse within the nuclear industry.

Decontamination
Effective decontamination is of interest for direct free release of material. Such a decontamination should therefore produce a minimum amount of secondary waste. Chemical and electrochemical decontamination of steel parts with phosphoric acid have proved to fulfil these aims. Recent experience with dismantled components from the reactor building demonstrates the effectiveness of the electropolishing technique, especially for stainless steel material.

Melting

The main advantages of melting contaminated metal are the homogenization of the radionuclides allowing representative sampling and the separation of distinct radionuclides from the metal, eg, cesium disappears totally from the melt and concentrates in the slag and filter dust; cobalt remains mainly in the melt. Ce-144 (found completely in the slag), manganese, zinc and europium left the melt as well. The different behaviour of the radionuclides can be explained by the different vaporization temperatures and the different chemical behaviours.

2.2. DEVELOPMENT OF THE "ONION" MELT TECHNIQUE

Since 1989, this development has been carried out successfully in a special melt facility working under radioprotection conditions at Siempelkamp Gießerei, Krefeld: in particular, it was demonstrated that higher radioactive steel can be enveloped by layers of lower radioactive steel in a so-called onion cast.

About 300 Mg of low-level steel (up to 500 Bq/g) have been melted, allowing assessment at industrial-scale level of
- the occupational irradiation exposure
- the possibility of nuclear recycling of the melt product, eg, as transport and/or storage packages
- the onion technique combining low with higher radioactive steel.

The highest dose rates were measured on the drums surface containing cut steel parts from KRB-A (1000-1500 μSv/h). During melt work, the average dose rate measured was 250 μSv/year.

3. DEVELOPMENT OF A LARGE WASTE STORAGE PACKAGE SUITABLE FOR THE KONRAD MINE

Research work has been carried out by GNS and Siempelkamp Gießerei (*i.e.*, the contract partners of CEC and KGB) relating to the development and qualification of a large nuclear waste package suitable for the possible disposal in the Konrad mine after interim storage at Gundremmingen and/or Gorleben (last status is that this could be possible by 1995). Half of Konrad Type VI container was taken as a basis (fig. 1), so that the storage volume of one Type VI container (1600 . 2000; 1700 high mm) can be occupied twice.

3.1. MATERIAL REQUIREMENTS

To make sure the container will meet the requirements for transport, storage and final disposal, the following mechanical properties are to be met: a yield stress of > 210 N/mm^2, a tensile strength of 250 N/mm^2 and an elongation of ≥ 3 %. The prototype for the qualification test has therefore been designed under conservative conditions, *i.e.*, the chemical composition was chosen to be at the upper limit. Consequently, the mechanical properties are at the lower range of the specified values.

Of major importance is the ultrasonic test, which makes sure that no allowed shrinkage within the wall either reduces the shielding effect of the container or reduces the strength of the wall to withstand shocks. A dye-penetrant test can make sure that no cracks are present in highly forced areas, such as the corner fittings necessary for handling.

3.2. PACKAGE CONCEPT

Based on the half Konrad Type VI Container (Fig. 1), the package is obtained as follows:

- casting of the container itself by using up to 50 % of contaminated steel < 74 Bq/g;
- charging it with nuclear steel parts > 500 Bq/g, previously segmented to fit the highest possible load factor;
- pouring (in several steps) of molten low-level steel < 200 Bq/g to occupy the inside space as close as possible at 100 %.

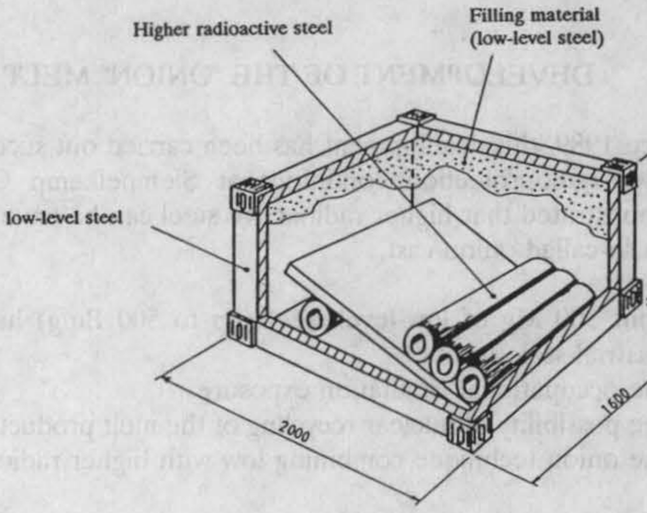


Fig. 1: Half Konrad Type VI
as monolith type package

The pouring in several steps gives several cast layers (similar to the onions) enveloping completely the previously introduced steel parts. The result of this is a nearly homogeneous and compact *i.e.*, monolithic steel block. The feasibility of the concept will be tested by manufacturing a prototype container out of non-radioactive material followed by a series of 5 containers which will be poured with radioactive material from the KRB-A steam dryer.

3.3. KONRAD REQUIREMENTS

The outer geometrical requirements are: 1600 mm X 2000 mm; and 850 mm high. The wall thickness may vary between 130 to 150 mm depending on the needed self-shielding effect. The package cover will contain a pouring hole.

The basic design is based on a wall thickness of 150 mm (giving an empty weight of 10850 kg). Taking an average filling factor 0.3 (depending on type of charged material) a steel mass (7.8 g/cm^3) of 2761 kg could be loaded. An average density (2761 kg/1180 dm^3) of 2.3 g/cm^3 of the inside volume gives a cast iron filling mass of 6071 kg (7.35 g/cm^3).

The average density of the complete payload mass is in this case 7.4 g/cm^3. The problem is not to exceed an overall total weight of 20 Mg (Konrad requirement). This can be achieved, even with an average filling factor of 0.54 (instead of 0.3).

The container shall be classified as IP2-package in the IAEA rules for transportation of radioactive material and as "Class I container" in the provisional Konrad disposal requirements and therefore has to withstand a charge of 10 N/mm^2 and shall not be burnable.

The content is defined page 7 (Blatt 7) of the GGVS (German ordinance for transport of dangerous goods by road), *i.e.*, low-level material defined as LSA III ($< 3.5 \times 10^{13}$ Bq of Co-60 per package). In the special case of the monolith type package, a Co-60 activity limit of 5.5×10^{12} Bq can be expected.

The average dose rate on the package surface can rise to 2 mSv/h and at 2 m distance it has to be < 0.1 mSv/h.

3.4. GORLEBEN REQUIREMENTS

For a possible interim storage in the "Abfallager Gorleben" (ALG), the corresponding activity limit is 9.25×10^{11} per package (25 Ci). A specific activity limit of 10^{10} Bq/g has been asked for (Nutzungserweiterungsstufe II). The qualification procedure of the package will be carried out with the competent authorities, *i.e.*, GAA Lüneburg and TÜV Hannover. The dose rates are the same as given in the GGVS.

3.5. PROTOTYPE QUALIFICATION TESTS

A prototype package will soon be tested in the framework of the qualification procedure by the BfS ("Bundesamt für Strahlenschutz" - Licensing Authority for the Konrad mine).
The tests will be carried out with respect to the relevant transport and storage requirements. While the IAEA regulations for the transport of IP2 packages are well known, the final disposal regulations for the Konrad mine are always in draft form. Over the next years, this situation may not be improved. At present, IAEA regulations require a drop test from a height of 0.3 m, whereas the Konrad conditions require 0.8 m drop tests. Konrad requires a fire test, which is not in the IAEA regulations; IAEA requires a waterspray test, which is not needed for Konrad (requiring tests of the corner fittings for loads on top of the container and, for special purposes, the tightness of the container must be demonstrated).

For the prototype, the harder conditions for each case will be chosen, *i.e.*,
- drop test from a height of 0.8 m
- fire test at 800°C for one hour (probably not relevant)
- staple test by loading (120 Mg) on top of the container (20 Mg)
- spreader handling test to check the corner fittings
- dye-penetrant tests to ensure that no cracks are present.

4. APPLICATION ON KRB-A PILOT DISMANTLING

The main parameter governing the number of packages (Table 1) with given outer dimensions and maximum weight are the quantity of radioactivity of the material to be charged, the payload and the filling factor.

The charging process needs transport of the void Monolith Type Package (MTP) from the foundry to the dismantling site where the charging of radioactive steel parts (> 500 Bq/g) is carried out. The MTP is then transported back to the foundry in order to pour lower radioactive material (< 200 Bq/g) inside the container to fill out the remaining free volume. Due to this, a MTP can be considered as an homogeneous radioactive source.

4.1. REACTOR COMPONENTS INVOLVED

KGB Gundremmingen envisages dismantling the following components:

Steam dryer (20 Mg)

The steam dryer (steel tubes and sheets) could be (after appropriate segmenting) charged in 5 MTPs, *i.e.*, 4 Mg of material in each. Based on an available volume of 1180 dm^3 the filling factor would be 4000 kg / 7.8 kg/dm^3 . 1180 dm^3 = 0.43.

Core shroud support (1.1 Mg)

This component could easily be charged in 1 MTP container with a filling factor of 0.12. This very low value could be changed by loading other steel parts with similar radioactivity.

Core shroud middle part (5.6 Mg)

This component cannot be completely charged in the given container due to the high radioactivity of its middle part. Therefore, 1/3 from above and 1/3 from below (5.6 Mg in total) have been found to be suitable for charging in 2 MTPs with filling factor of 0.3.

Reactor Pressure Vessel (RPV) middle part (62 Mg)

Considering the middle part of the RPV (4.9 m high) several charging options have been examined, the most appropriate option (Fig. 2) being chosen for the following reasons:

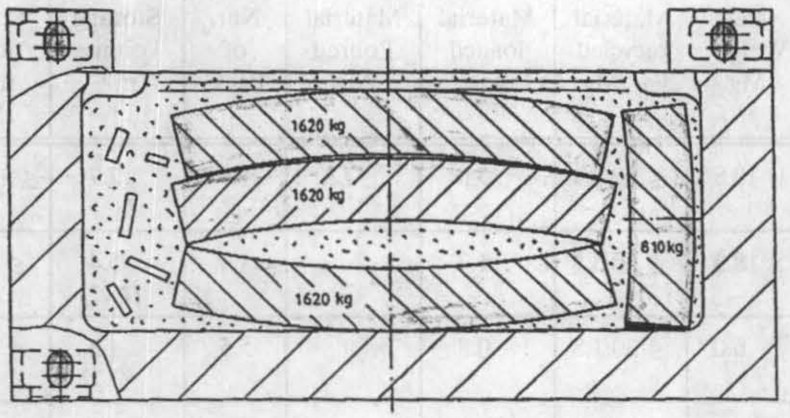
- easier segmenting of RPV
- more space for using remote charging device
- more volume for pouring material.

For this option, 13 MTPs would be needed with a filling factor of 0.54. Besides 62 Mg of the RPV-parts, about 9.8 Mg of pouring material could also be conditioned.

Table 1 : Number of packages needed for various KRB-A reactor core components.

Component	Mass (Mg)	Nbr. of packages	Filling factor
Steam dryer + water separator	20	5	0.43
Core shroud support	1.1	1	0.12
Core shroud (middle part)	5.6	2	0.30
RPV (middle part)	62	13	0.54
	88.7	21	

Fig. 2: Application to RPV (6 parts of 1620 kg + 12 parts of 714 kg + 13 parts of 248 kg)



Container weight	10.85 Mg
Payload (theor.)	9.15 Mg
Payvolume	1.18 m^3
Filling factor	0.54
Overall package weight	≤ 20.00 Mg

4.2. DOSE RATE ESTIMATION FOR CHARGED PACKAGES

The highest radioactivity is given by the RPV for which first activity calculation was made in 1977 followed by measurements in 1987 and again calculation in June 1992. Nearly 85 % of the activity distribution is in the first inner 50 mm of the wall. By taking an average value of 2.848 x 10^4 Bq/g and a filling factor of 0.54 a specific volume activity of 1.2 x 10^5 Bq/cm^3 is obtained. Taking into account the shielding effect of the 150 mm container wall, the following dose rates are found:

at surface	→	0.052 mSv/h	(2.0 mSv/h authorized)
at 1 m	→	0.040 mSv/h	(0.1 mSv/h authorized)
at 3 m	→	0.960 mSv/h (without shielding)	(10.0 mSv/h authorized)

The RPV parts are charged in a way that the higher active side is always oriented toward the inside, (Fig. 2) thus giving an additional selfshielding effect. In this case, the container wall thickness of 150 mm seems optimal. A reduction to 130 mm (giving higher payload) does not reduce the number of containers, as may be possible in the case of other components.

5. COMPARISON WITH OTHER CONDITIONING POSSIBILITIES

In order to obtain a rough view, the considered KRB-A waste masses (88.7 Mg) are compared with respect to the number of packages (suitable for the Konrad mine) needed. The different conditioning techniques, transport and storage costs are not taken into account.

Table 2: Global comparison with existing containers.

1) Container Type	Net Weight Mg	Material recycled % /Mg	Material loaded Mg	Material Poured Mg	2) Nbr. of Pack.	Storage volume m^3	Conditioned mass Mg	Note
Monolith type package	10.8	≤ 50/5.4	5.0	3.8	1.0	2.7	≤ 14.2	
Cast iron type VI	18.3	≤ 30/5.5	1.7	-	1.9	5.4 *(10.3)*	≤ 7.2	
MosaikII 15 Type B (U)	6.0	≤ 30/1.8	0.8	-	5.5	1.3 *(7.1)*	≤ 2.6	
Concrete 3) type V	13.7	-	6.3	-	2.2	10.9 *(24.5)*	6.3	

1) container wall 150 mm
2) with respect to 1 monolith type package
3) shielding not sufficient in some cases

6. CONCLUDING COMMENTS

A large quantity of KRB-A reactor steel components could be disposed of by saving costly storage volume and by using low-level steel waste to produce storage/disposal packages. This is obtained by a particular melting technique (onion technique) giving a monolith type package as the void volume inside can nearly be completely poured with steel waste up to 200 Bq/g.

In the case of the KRB-A reactor components, to be dismantled in the framework of a CEC pilot project (88.7 Mg to be disposed of), 21 of the monolith type packages would be needed. At the same time, about 93 Mg of low-level steel waste could be disposed of by pouring the container with the onion technique.

The monolith type package is being qualified for final storage in the Konrad mine in container class I (Abfallbehälterklasse I). For transport, the GGVS requirements foresee the category IP2. The possibility that these packages will be used in the framework of the KRB-A pilot dismantling depends on the competent German Authorities for the Konrad mine.

The qualification procedure (under way) could be finished before the end of this year. As regards the industrial aspect of the recycling/reuse of steel from refurbishing/decommissioning of nuclear installations in Germany, it may qualify as one of the most successful with EC participation. Until now, > 3000 packages [mainly Mosaik II Type B(U)] for various waste categories have already been produced and are under use by various nuclear power plants. Another 500 per year are being manufactured, each one made of up to 30 % of radioactively contaminated steel.

With a view to the Greifswald nuclear power plant (WWER) decommissioning, another 3000 to 4000 Mosaik II containers could be needed.

This is a clear indication that recycling of nuclear steel waste is a realistic route to reduce the radioactive waste volume and to save storage volume.

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