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Copper canister with cast inner component

Amendment to project on Alternative Systems Study (PASS), SKB TR 93-04

Lars Werme, Joachim Eriksson

Swedish Nuclear Fuel and Waste Management Co, Stockholm, Sweden

March 1995

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ABSTRACT

The Project on Alternative Systems Study, PASS, was described in a report dated october 1992. In the report, the reference repository concept KBS-3 is described together with three other alternatives. In the report several designs for fuel storage canister are presented. This report describes a recently developed design for the inner component of the composite, steel and copper, canister which is the main alternative in the KBS-3 model. The new design will be manufactured by casting. A cast insert with inner walls eliminates the need for a stabilizing filler in the canister and guarantees that the fuel remains sub-critical during sufficient time in the repository. The cast insert is judged, to, in comparison with the steel tube alternative, lead to a considerably simplified process in the encapsulation plant and lower development and investment cost. Positive side effects of the design are that the mechanical strength is improved by a factor 2-3 and that the difficult filling operation is avoided in the encapsulation process. The drawbacks are higher weight and probably higher unit price for the empty canister.

SAMMANFATTNING

Slutrapporten för "Project on Alternative Systems Study", PASS, publicerades i oktober 1992. Rapporten beskriver det idag gällande slutförvaringsalternativet KBS-3 tillsammans med tre andra alternativ. I rapporten presenteras flera alternativa utföranden av behållaren avsedd att användas till slutförvaringen av det utbrända kärnbränslet. Denna rapport beskriver ett nytt utförande av insatsen till kapseln i koppar/stål utförande. Designen betraktas som huvudalternativ i KBS-3 modellen. Utförandet presenterat i denna rapport har en insats tillverkad genom gjutning. En gjuten insats med innerväggar eliminerar behovet av stabiliserande fyllning i kapseln och garanterar att bränslet är underkristiskt under erforderlig tid i djupförvaret. Den gjutna kapselinsatsen bedöms, vid jämförelse med stålrörs alternativet, medföra avsevärt förenklad inkapslingsprocess och lägre utvecklings- och investeringkostnad. Positiva bieffekter är också att kollaps lasten ökar två till tre gånger och att ett komplicerat processteg undviks. Den tydligaste nackdelen är ökad totalvikt och förmodligen högre styckepris för den tomma kapseln.

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1   BACKGROUND

In Project on Alternative Systems Study, PASS, alternative repository systems for deep disposal of spent nuclear fuel were compared. The comparison was made of different layouts of the repository as well as of different canister designs. The work was reported in October 1992 /1/. In the report, the reference repository concept KBS-3 is described and evaluated together with three other systems. These systems are Medium-Long Tunnels - Medium-Long Holes (MLH), Long Tunnels - Very Long Holes (VLH) and Deep Boreholes - Very Deep Holes (VDH). In the KBS-3 system, the canisters are emplaced one by one in vertical bored holes in the floor of a deposition tunnel. The MLH system employs the same canisters as the KBS-3 system, but emplaces them at the centre of horizontal bored tunnels. The VLH system uses a few very long, full-face-bored tunnels for disposal of large canisters, while in the VDH system canisters are stacked on top of each other in deep holes (2-4 km).

Both the repository layout and the proposed canister alternatives were compared and ranked. For the canisters, the ranking considered long-term performance and safety, technology, i.e. fabrication , filling and sealing, and costs. The conclusion was that a copper/steel canister was ranked higher than the other alternatives.

This reference canister is made of a steel tube with an outer shell of copper, 50 mm each in wall thickness. The function of the steel tube is to withstand the load caused by bentonite swelling and groundwater pressure, 10 MPa. The planned deep repository will be located 500 m below ground level. Copper is used for the outer shell because it has a very low corrosion rate under the KBS-3 repository conditions.

The issue of criticality was not addressed in the PASS report, but has been elaborated in the continued studies. If no filling is applied around the fuel in the canister, there will be a free volume of 1.2 m^3 inside the canister. If water should leak into the canister and fill this void volume, the fuel configuration could under certain circumstances reach criticality. To avoid this possibility, it is necessary to fill the remaining volume with a filling material. Possible filling materials are glass beads, copper spheres or magnetite /2/. The filling operation is a technically demanding process. An adequate filling fraction must be achieved and verified. At the same time the atmosphere inside the steel canister must be changed to a rare gas (see below). There is also the risk that fine particles of the fill material might interfere with the final lid welding. All this makes the use of an alternative

solid piece inside the copper component an attractive option. In this report a cast inner container with separate channels for the fuel elements is described and discussed.

2 DESCRIPTION OF THE CAST INNER COMPONENT

The inner component of the copper/steel canister can be manufactured through casting. The material could be iron, steel or a non-ferrous metal. Instead of a tube the inner component will be a cast solid with square channels for the fuel, see figure 2-1.
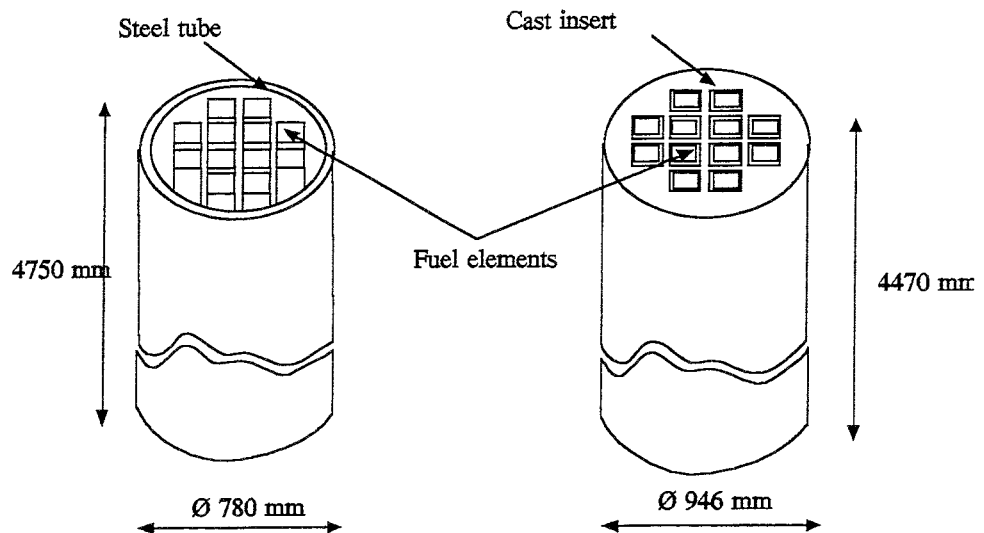
Figure 2-1. Comparison between steel tube (left) and cast (right) inner component.

The design is shown in more detail in appendix 1.

The first alternative is to manufacture the inner component by a single casting to which the lid and bottom is welded or bolted. A second alternative is to cast it in two parts which are welded together. This is somewhat more difficult because it gives an extra weld which will probably need inspection and also require the use of the a weldable and more expensive casting material.

There are two material types that are considered as main alternatives: cast steel, grade SS 1306 and spheroidal graphite (ductile) cast iron, grade SS 0717 (see table 2-1 for chemical specification).

Table 2-1. Chemical specification for the two material alternatives for the cast inner component.

SS 07 17(iron)	C	Si	Mn	P_{max}	S_{max}	Ni	Mg
%	3.20	1.5-2.8	0.06-1.0	0.08	0.02	0-2.0	0.02-0.08

SS 13 06 (steel)	C	Si	Mn	P	S	Cr	Cu
% Max	0.18	0.60	1.10	0.036	0.03	0.30	0.30

These two materials have been ranked and compared with regard to fabrication, costs and long-term performance. At this time, the judgements must be based on the best estimates that are possible from the available data.

Castability and weldability have been considered for fabrication. Weldability is of secondary importance since high quality welds will only be required if half-length canisters are cast. The bottom weld is only a seal weld, which is not required to have a long service life. It should only provide a leak-tight seal during the final lid welding of the outer copper canister. The fabrication and sealing of the outer copper shell is identical for the two alternatives and does not influence the ranking.

Long-term performance considers items such as corrosion resistance, ductility and compressive strength. There are at present insufficient data available to fully compare and rank the two materials with respect to corrosion performance. A preliminary assessment indicate that there is no reason to expect any major differences in corrosion performance between the two cast materials (see below). However, further studies of the anaerobic corrosion of cast iron will be required before a proper ranking can be made.

Because of the lower cost of cast iron compared to steel together with its better castability, cast iron is from a cost point of view a more advantageous alternative.

The ranking is summarized in table 2-2.

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Table 2-2. Ranking of cast insert canister alternatives. A ranking of 1 is the best.

Material	Cast steel	Cast iron
Fabrication	2	1
Costs	2	1
Long-term performance	1	*

* cannot be ranked due to incomplete data.

The total weight increases considerably for the new canister, see comparison in table 2-3.

Table 2-3. Weight comparison for canister with cast inner component.

Type	Copper	Inner Comp	Fuel	Filling	Total
Cast BWR	7500 kg	13500 kg	3600 kg	0 kg	24600 kg
Cast PWR	7500 kg	16500 kg	3600 kg	0 kg	27600 kg
Steel tube	6300 kg	4800 kg	3600 kg	2300 kg	17000 kg

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3   REQUIREMENTS ON THE CANISTER

The canister is intended to isolate the waste for a very long time. The different aspects that have to be taken in account are presented below.

3.1   LONG TERM PROPERTIES

3.1.1   Mechanical strength

Preliminary calculations indicate that the canister collapse pressure for increases two to three times with the cast inner component compared to the steel tube /3/.

3.1.2   External corrosion

The inner component does not affect the basic design of the outer copper shell. The corrosion resistance is therefore assumed to be unchanged as long as the outer shell remains undamaged.

3.1.3   Internal corrosion

Measures will be taken to ensure that the interior of the canister is dry. However, some remaining water may occur in the fuel elements. With air and water inside the canister, the intense gamma-field will by radiolysis produce nitric acid. The rate of radiolytic production is slow and the amounts of acid produced will be limited by the availability of nitrogen, oxygen and water /4/. Nitric acid could threaten the canister's integrity stress corrosion cracking. The air can be evacuated and replaced by a rare gas, which would minimize the acid production /5/. There is no reason to expect cast iron to be markedly more sensitive to stress corrosion cracking than carbon steel. However, with the cast iron inner component, there is no need for a filler material, which thus eliminates the risk for introducing additional water and air sorbed to the surfaces of the filler particles.

3.1.4   Corrosion after break-through

In the case of water intrusion, hydrogen producing corrosion will occur.

Within the SKB programme, there are limited data on the anaerobic corrosion of ductile cast iron. However, a study performed for NAGRA, Switzerland, show that there is no reason to believe that the corrosion rate should be different from that of low carbon steel /6/. The total canister surface area is larger and the production rate of hydrogen will increase in proportion to this area increase. This corresponds to little over a two-fold increase. However, even the lower production rate is high enough to cause two-phase flow. Therefore, there is no difference in principle between the two canister designs, albeit the amount of hydrogen to be transported away is larger for the cast iron concept.

3.2   CRITICALITY

Preliminary criticality calculations for one BWR and one PWR canister fuel configuration (see Figure 4-1) have been performed /7/. In the BWR case, the calculations were performed assuming 12 unirradiated Svea-64 fuel elements with 3.6% ^{235}U, and in the PWR case 4 unirradiated 17x17 fuel elements with 4,2 % enrichment. The results obtained indicate that subcriticality could be achieved under all circumstances even for such highly enriched fuel if a certain burnup of the fuel is taken into account. This burn up corresponds to about one irradiation cycle and is small compared to normally irradiated fuel. However, more detailed criticality calculations will have to be performed before final conclusions can be made.
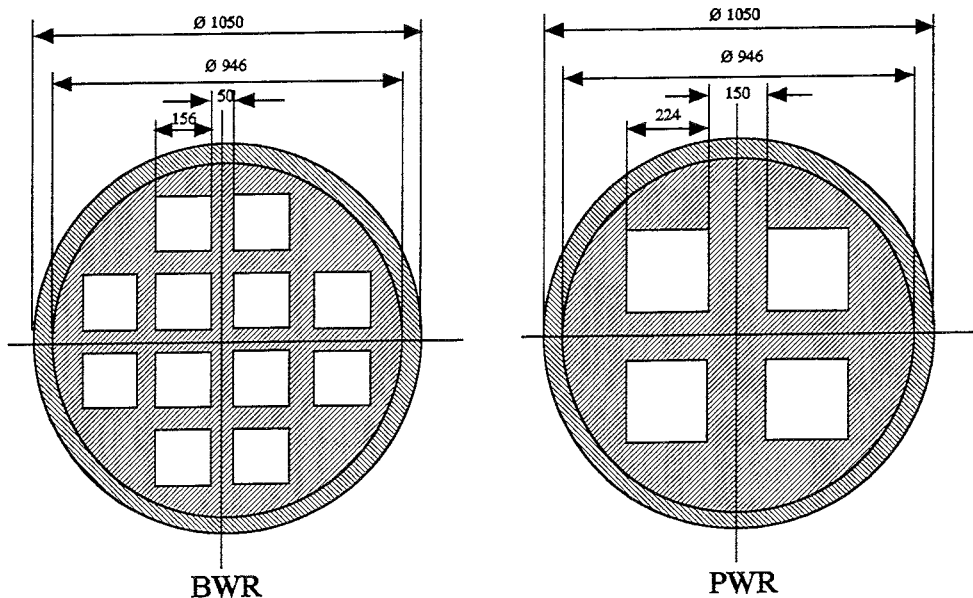
Figure 4-1. Storage configuration in cast inserts for BWR and PWR type fuel.

3.3 HEAT TRANSFER AND RADIATION DOSE

The radiation dose that the canister surroundings are exposed to is lower for the cast component compared with the steel tube due to the larger cross section area. The larger surface area of this canister will also allow a slightly higher residuel power in the fuel elements in the canister, which will give a higher flexibility in the choice of fuel elements.

3.4 MANUFACTURING FEASIBILITY

The cast component can be made in a sand mould using chemically bonded sand. Sand mould casting is the conventional method for products with a complicated geometry of this size.

There are a number of foundries both in Sweden and abroad with capacity to handle the required weight, either at present or after a limited investment.

4 EFFECTS ON ENCAPSULATION PLANT AND FINAL DISPOSAL

4.1 PROCESSES IN THE ENCAPSULATION PLANT

In the pool area at the front end of the encapsulation plant, the intent is to perform measurements of the reactivity of the fuel. With a cast inner component, less elaborate measurements will be required, since the safety margins against criticality are larger than for the steel tube alternative.

The emplacement of the fuel elements in the canister is facilitated with a cast inner component since there will be no need for a device for guiding the fuel elements during loading. The need for a filler material and all handling phases connected with this, such as replacing the air with a noble gas in the filler material, will be eliminated. In case of recovery of the fuel from the canister, there will be no need for removing the filler material, which to a large extent complicates the procedures in the encapsulation plant. Furthermore, all systems and equipment for receiving, storing and conditioning the filler material will be unnecessary. The cast inner component therefore lead to, in comparison with the steel tube alternative, a considerably simplified process in the plant, with lower development and investment costs as a result.

The cast inner component makes the canister heavier, which affects the handling equipment. To some extent, this is compensated by the fact that with maintained copper thickness, the requirements on radiation shielding are lower. The steel lid will be lighter and easier to handle.

The procedures for emptying a canister with an unacceptable copper lid sealing weld has a potential for being simplified considerably.

The possibilities for sealing the inner component with bolts rather than welding are increased considerably.

4.2   HANDLING AND DISPOSAL IN THE REPOSITORY

The increase in size does not give any effects on the handling system in the deep repository. The deposition tunnel height can be reduced, but the width has to be increased. The total effect of this is a reduced cross section area, which gives a cost reduction. The vertically bored deposition holes will also be subject to changes, increased diameter and reduced depth. The costs will probably increase because the consumption of bentonite increases. The dimension change will lead to savings in the boring because the reduced depth has a greater impact on the total cost than the increased diameter. The increased dimensions makes it also possible to have higher thermal load per canister.

The weight has no impact on the deposition operation except that the lifting grip on the copper lid has to be redesigned for the higher load.

5 COST ASPECTS

It is not yet possible to accurately assess the economical effects of introducing the cast inner component. The purpose of this chapter is to indicate whether the design change is likely to lead to a cost increase or decrease. As will be seen below, costs will increase in some cases, but changes are very small compared with the total cost for the encapsulation and storage facilities.

5.1 CANISTER COST

The consumption of copper increases with the new design, but this is to some extent compensated by a lower price for the inner component. Savings are made in some areas such as: reduced total weld length and elimination the fuel rod storage rack inside the steel tube. If cast iron is chosen the price per unit will probably be slightly higher than the previous design. If cast steel is chosen the cost will increase further.

5.2 THE ENCAPSULATION PROCESS

Since the cast canister has a larger diameter and higher weight. The costs for handling will increase. However the elimination of the filling process will probably lead to a far greater reduction in cost. It is expected that this simplification has the greatest total cost impact.

5.3 THE REPOSITORY DISPOSAL

The shorter and wider canister gives corresponding effects on the deposition tunnel dimensions. This results in a tunnel with a smaller cross section area, which leads to cost reductions. The costs for the deposition hole also decreases because the reduction of hole depth has larger impact on costs than the incase i diameter.

The consumption of bentonite buffer material increases because of the increase in canister diameter.

6   CONCLUSIONS

The consequences of introducing the cast inner component are summarized below:

Positive consequences

- Preliminary calculations show that the risk for long term fuel criticality is probably eliminated. This is to be confirmed by more precise calculations.

- The filling operation is avoided in the encapsulation process.

- The new design increases the canister compressive strength pressure two to three times[1].

- There is no reason to expect cast iron to be markedly more sensitive to stress corrosion cracking than carbon steel.

- Costs for handling and storage will increase, but this will probably, to a large extent be compensated by lower costs in the encapsulation process.

Negative consequences

- The unit price will probably be higher.

- The canister weight increases by 7,5-10,5 tons[1].

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[1]Variation depends on fuel type and chosen material.

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Appendix 1

Ø 1050

Ø 950

A

A

B

B

4470

4833

A - A

Ø 156

50

B - B
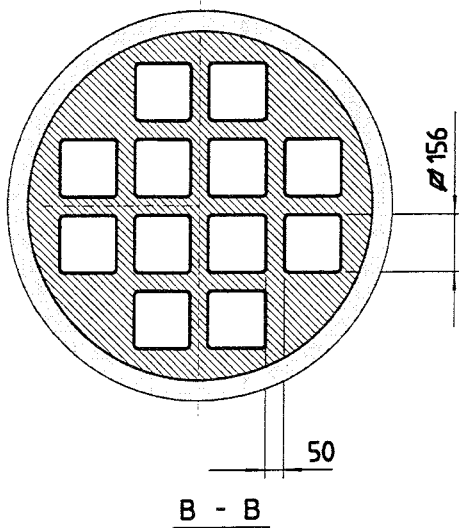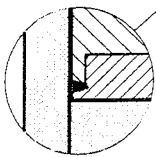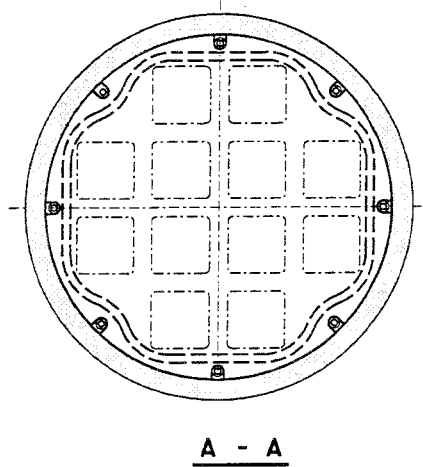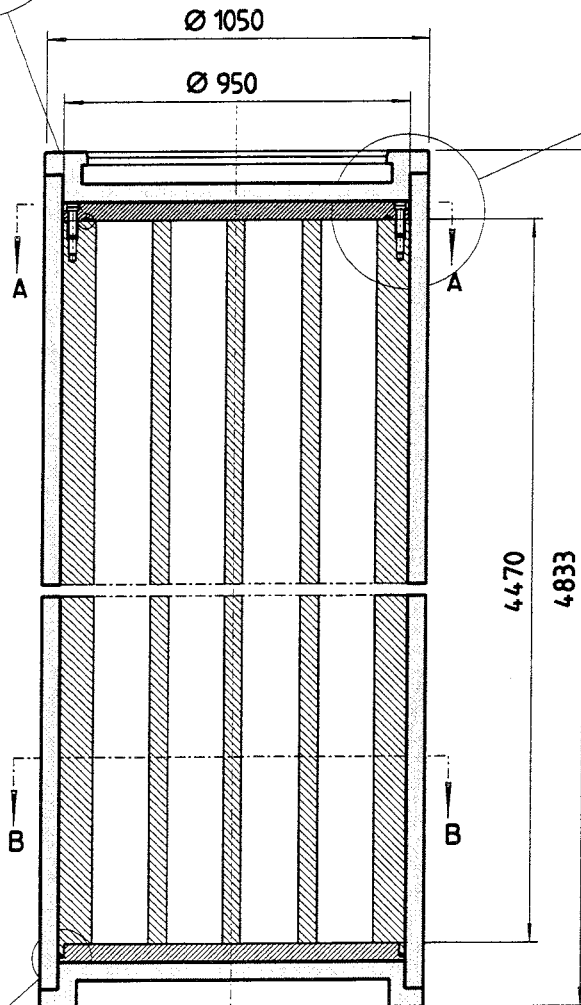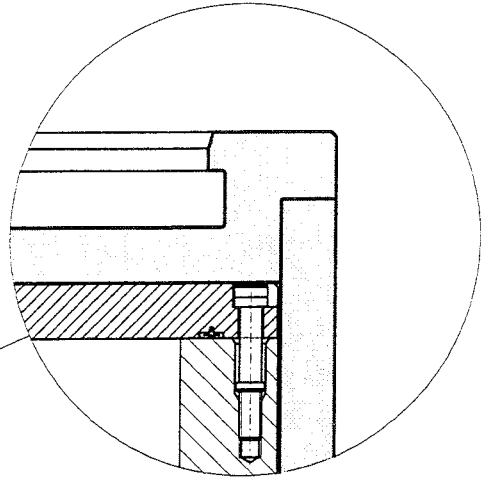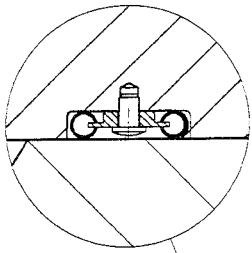
Canister surface (m²)	17.67
Estimated weight (kg)	
Copper canister	7 410
Insert	13 610
Fuel assemblies	3 640
Total	24 660

REV	NO	NOTE		DRAWN	DATE

CANISTER

BWR type with cast insert
Preliminary

DRAWN	DESIGNED		CHECKED	REG NO	
GF	GF		LW	342C-205	

DATE		SYSTEM NO	DRAWING NO	REV
95 02 07		278	Skiss 002	

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[1] Royal Institute of Technology, Department of Inorganic Chemistry, Stockholm, Sweden
[2] Universidad Politécnica de Cataluña, Departmento de Inginería Química, Barcelona, Spain
[3] MBT Tecnología Ambiental, Cerdanyola, Spain
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