NUCLEAR SHIELDS

Case study

B(U) Package design of transport / storage cask for CSD-V canisters

Companies involved

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Transport & handling

This vitrified waste package has been designed to transport a single vitrified waste canister over public road, train and sea. Costs of transport will be decreased due to the possibility of standard transport on a truck over public road. A customized pallet has been developed to allow direct attachment of the package to the transportation vehicle. Four stabilizers will be attached from the pallet to the cask to prevent any movement.

The lid of the cask is capable of lifting the entire package. The lid can be placed onto the cask, after which the entire package can be placed on the pallet. A 20 ton capacity industrial crane is required to pick up the package, as the complete package has a tare weight of 18.000 kilos.

Shock absorbers have been added to both the top and bottom of the package to provide protection during accidents. An outer structure has been added between the two shock absorbers to provide additional protection to the inner containment. The ribs of the outer structure also function as connection points for the stabilizers.

Radiation shielding & materials

The shielding of the cask has been optimized with the aim of complying with the limiting values according to IAEA/ADR while keeping the total mass as low as possible. The basis of the optimization studies was a notional CSD-V canister, which represents the worst case of all canisters ever handled by German companies with regard to the radionuclide inventory (more information on the inventory below). By means of this worst-case activity inventory, two shielding configurations were developed, one for non-exclusive use with a maximum dose rate on the cask surface of 2 mSv/h and one for exclusive use with a maximum dose rate of 10 mSv/h.

The shielding consists of two layers, the innermost layer being made of polyethylene, which serves to moderate the high-energy neutrons emitted by the vitrified waste. The outer layer is made of lead and shields the moderated neutrons and the photons from the glass matrix as well as the secondary photons generated by neutron capture. Thus, the procedure of optimizing the shielding is considered a two-dimensional parameter study whereby multiple contributions for each configuration have to be accounted for.

The shielding was designed by Dr. J. P. Dabruck, D-NUCS Nuclear Simulations, using the approved Monte Carlo code MCNP 6.2.

Activity Inventory - Photon-Emitting Nuclides

Only medium- and long-lived nuclides are relevant for the dose rate of actual waste containers. Of these nuclides, only those are important whose photons have a comparatively high energy and intensity per decay. Since the activity inventories of the CSD-V canisters handled by German companies are well documented, the relevant nuclides can be extracted from these documents. The following table lists these nuclides, their half-life, photon intensity and worst-case activity. The worst-case activity applies to each nuclide individually, i.e. the highest activity ever occurring in all canisters was determined for each individual nuclide. The nuclides therefore need not necessarily have occurred in one and the same canister with these activities.

Nuclide	$T_{1/2}$ [a]	Intensity	A_0 [Bq]
^{60}Co	5.27	2.000	4.67E+12
^{94}Nb	20,300.00	1.98	1.59E+08
^{134}Cs	2.06	2.23	1.36E+15
^{137}Cs	30.07	0.85	6.41E+15
^{154}Eu	8.59	1.67	2.33E+14
^{243}Am	7,370.00	1.54E-05	2.23E+12

Table 1: Worst-case activity inventory of photon-emitting nuclides in a CSD-V canister

After performing the first photon transport simulations, it is determined that only ^{60}Co, 134Cs-and 154Eu lead to significant contributions to the dose rate outside the cask.

Activity Inventory - Neutron-Emitting Nuclides

In the case of neutrons, the identification of relevant nuclides, the determination of the neutron source strength and, in particular, the energy spectrum is much more complex, since neutrons are not only emitted during nuclide decay through spontaneous fission, but also to a significant extent through secondary nuclear interactions, such as the capture of alpha particles in so-called (α,n) reactions.

The continuous neutron spectrum, which implicitly contains all these contributions, is required to optimize the shielding. This is taken from an external reference in which the neutron spectrum was determined by means of burnup calculations for a BWR fuel element for various times and reactor parameters. It has been shown that the shape of the spectrum practically does not change at least over a period of 15 years. A comparison with the Watt fission spectra of the individual spontaneous fission nuclides has shown that the overall spectrum used here is conservative.

The source strength of the emitted neutrons is also determined using this reference. Since the individual contributions of all neutron-emitting nuclear reactions to the overall spectrum are not known, the determination of the source strength is not trivial. However, since the most important nuclide with respect to neutron emission is ^{244}Cm in both the irradiated BWR fuel element and the CSD-V canisters, the corresponding ^{244}Cm-inventories can be correlated to determine the correct source strength of the worst-case canister:

$$S_{\text{CSD-V}}(t) = \frac{A^{\text{CSD-V}}_{\text{Cm-244}}(t_0)}{A^{\text{BWR-fe}}_{\text{Cm-244}}(t_0)} \times S_{\text{BWR-fe}}(t)$$

Details & Results of the Simulations

In order to find the optimal configuration, the thickness of the PE and lead shielding are varied independently. The dose rate contributions from all relevant sources (Photons, Neutrons and Photons from neutron capture) are calculated separately for each configuration and added up. The aim is to come as close as possible to the limiting values of 2 mSv/h or 10 mSv/h on the external surface of the cask without exceeding them.

The activities of the photon-emitting nuclides and the source strength of the neutrons are considered for a point in time of 5 years after vitrification, as this corresponds to the prescribed minimum cool-down time at the La Hague reprocessing plant.

According to the simulation results the optimal configuration of a cask for non-exclusive use consists of a PE layer with a thickness of 125 mm and a lead layer of 135 mm thickness. The shielding requirements for a container for exclusive use are lower, which is why the optimal configuration consists of 70 mm PE and 113 mm lead.

Table 2 shows the individual contributions to the dose rate on the outer surface of the containers for exclusive and non-exclusive use in their respective optimal configurations.

		non-exclusive	exclusive
	$D_{PE} + D_{lead}$ [cm] =	12.5 + 13.5	7 + 11.3
Source	**A [Bq]**	**[mSv/h]**	**[mSv/h]**
^{60}Co	2.42E+12	0.04	0.26
^{134}Cs	2.54E+14	0.15	0.95
^{154}Eu	1.56E+14	0.71	4.40
Subtotal Photons		**0.90**	**5.61**
Neutrons	8.32E+08	1.07	4.21
(n,γ) Photons		0.00	0.01
Subtotal Neutrons		**1.07**	**4.22**
Total Dose Rate		**1.97**	**9.83**

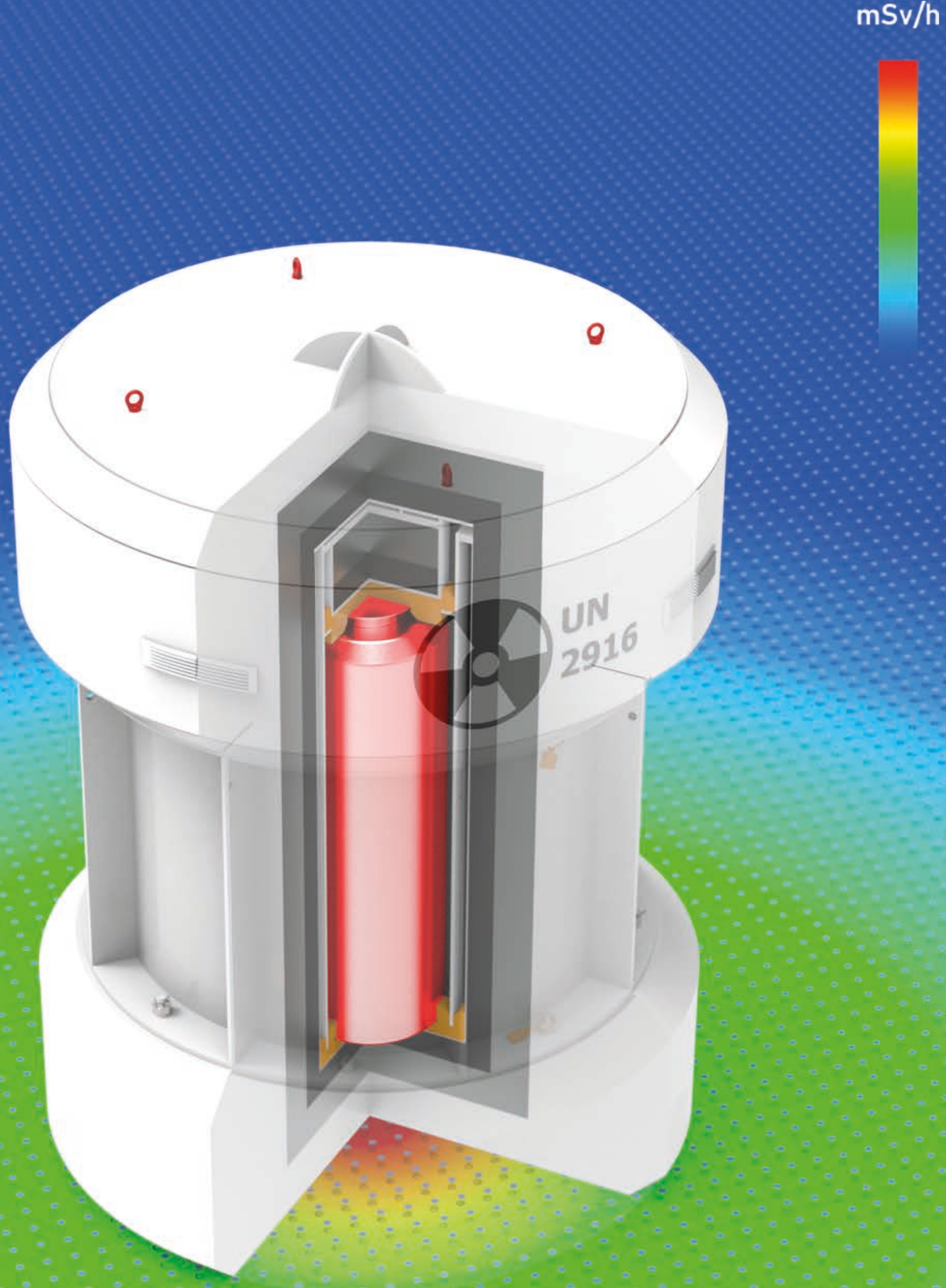
Table 2: Optimal shielding configurations and dose rate contributions

Cooling & heat resistance

Cooling of the package will be realized by utilizing the airflow caused by the heat generation of the vitrified waste canister. The airflow generated by the canister will cool the polyethylene shielding layer. This is necessary as polyethylene has a relatively low melting point (120˚C). Airducts have been created inside the construction to enable this airflow. The airducts are in research and development stage.

In addition, the steel inner liner will be coated with a liquid ceramic thermal insulation coating. This coating will optimize the airflow by reflecting the heat and slowing the heat absorption of the steel.

The outside of the package will be coated with a high heat coating to offer protection to external heat. This coating will provide protection to the surface from exposure to temperatures of up to 650˚C.



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