DISPERSION OF RADIONUCLIDES AND RADIATION EXPOSURE AFTER LEACHING BY GROUNDWATER OF A SOLIDFIED CORE-CONCRETE MELT

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ABSTRACT

After a core meltdown accident it cannot be completely ruled out that the melt will reach, and partly penetrate, the concrete foundation. The amounts of some radionuclides leached out by the passing groundwater are estimated. The tranport of dissolved radionuclides in groundwater is simulated by an analytical dispersion model; the underlying parameters are the hydrogeological characteristics of the Upper Rhine Valley. Simple models are used to estimate the ensuing radiation exposures for various exposure pathways. A number of technical and administrative measures are indicated which allow the radionuclide concentration in the groundwater and the radiation exposure to be reduced considerably.

PENETRATION INTO THE REACTOR FOUNDATION OF THE CORE CONCRETE MELT

Findings of the "German Risk Study, Phase B" indicate that a core meltdown accident could well cause the melt to penetrate into the reactor foundation and pass through it down to the bottom side of the foundation within five days. Even if the passing groundwater were to prevent complete melt-through, there would still be a direct contact of the groundwater with the resolidified melt surface through fissures, cracks, etc., which could cause the fission products to be leached.

For the purpose of this study, the distribution of fission products and activation products within the melt is assumed to be roughly homogeneous. Of the volatile fission products, 10% of the original inventory is assumed to remain in the melt, while it is 100% of the others. From the point of view of radiation protection, three radionuclides have been found to be important in investigations of the resultant radiation exposures: Sr-90, Tc-99, and Cs-137.

LEACHING OF THE RESOLIDIFIED MELT, RADIONUCLIDE TRANSPORT

The resolidified melt is assumed to establish a contact surface vis-a-vis the groundwater with a diameter of 16 m. Because of the gaps and fissures in the concrete it may be assumed, by a way of approximation, that the actual contact surface area will be roughly a factor of 10 larger than the postulated one.

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As the resoldified melt is probably less resistent to leaching than the glass specially developed for final storage, for which a leaching rate of 10^{-4} g/(cm^2 x d), was determined, this number is increased by a factor of 100; this means that the estimate is based on a leaching rate of 10^{-2} g (cm^2 x d). In the light of the leaching experiments meanwhile performed at the Karlsruhe Nuclear Research Center with slag arising from the BETA experimental facility, this number may be considered to be conservative.

The distribution in the groundwater of radionuclides as a function of time and space was determined by an analytical solution of the transport equation:

The Philippsburg Nuclear Power Station, which is located on the Upper Rhine River, was selected as the reference site. The relatively homogeneous structure of the aquifer of that site allows the transport equation listed above to be solved analytically for the radionuclide concentration to be determined in this way. Some important hydrogeological data of the Upper Rhine Valley are listed in Table 1.

Table 1: Hydrogeological data of the Central Upper Rhine Valley

Thickness of aquifer:	$M = 50$ m
Porosity:	$n = 0,2$
Migration velocity:	$v_a = 3,3$ m/d
Dispersion coefficients:	$D_x = 33$ m^2/d
	D_y, $D_z = 1,65$ m^2/d
Bulk density:	$\rho_b = 2,12$ g/cm^3

EXPOSURE PATHWAYS TAKEN INTO ACCOUNT

Six exposure pathways were taken into account in the detailed study /2/.

The results obtained for two exposure pathways are described below:
- The incorporation of drinking water from groundwater (800 l/a). The drinking water consists of contaminated groundwater from the environment of the reactor, the basic assumption being that no decontamination processes are employed.
- The incorporation of drinking water from river water (800 l/a). The drinking water is taken from the river, again under the assumption of no decontamination processes being used.

RESULTS

Figure 1a shows the concentration in the groundwater and in the river water 500 m away from the reactor between 100 days and 100,000 days. The groundwater was assumed to be discharged into the river water 500 m from the reactor, and the discharge rate of the river was assumed to be 1000 m^3/s.

The radiation exposures were determined on the basis of the concentrations found in the groundwater and in the river water. Figure 1b shows the effective equivalent dose for an adult. The following results were determined for groundwater:

Tc-99 is transported rapidly with the groundwater; it contributes to the radiation exposure practically throughout the entire leaching period. However, the radionuclide concentration and the effective equivalent dose of Tc-99 attain only relatively low levels of 10^6 Bq/m^3 and approx. 10^{-3} Sv/a, compared to the other two nuclides. This is a consequence, above all, of the small inventory of Tc-99.

The highest radionuclide concentration of approx. 10^{10} Bq/m^3 is reached by Sr-90 after some 5000 days. The effective equivalent dose for an adult is above 10^2 Sv/a. After a prolonged period of about 10,000 days, Cs-137 reaches a maximum of about 10^8 Bq/m^3. The effective equivalent dose for this radionuclide is approx. 1 Sv/a.

The groundwater is highly diluted when entering the river water. Consequently, concentrations will be lower, as will be the radiation exposures, by an approximated factor of 10^5.

COUNTERMEASURES

To limit radiation exposures by administrative measures, water extraction wells can be closed down, and the river water can be decontaminated in preparation of its use as drinking water.

Some technical measures, which may be taken to limit the spreading of radioactivity, are these:

- Installing impermeable walls around the plant.
- Pumping off the groundwater in order to dry the reactor foundation.
- Installing extraction pumps to prevent the groundwater from leaving the site.
- Making special use of soil freeze techniques.

In the light of those possibilities, it is meaningful to keep a set of decision-making methods ready in case a flexible intervention were required in a real accident situation.

REFERENCES

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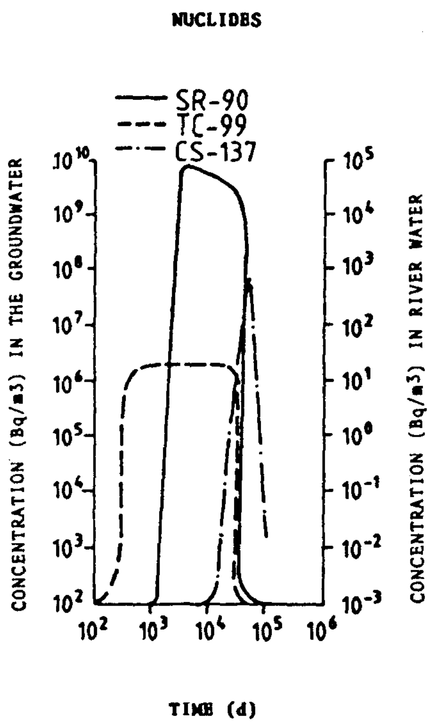

Fig. 1a:
Radionuclide concentrations in groundwater and river water; distance from the reactor, 500 m.

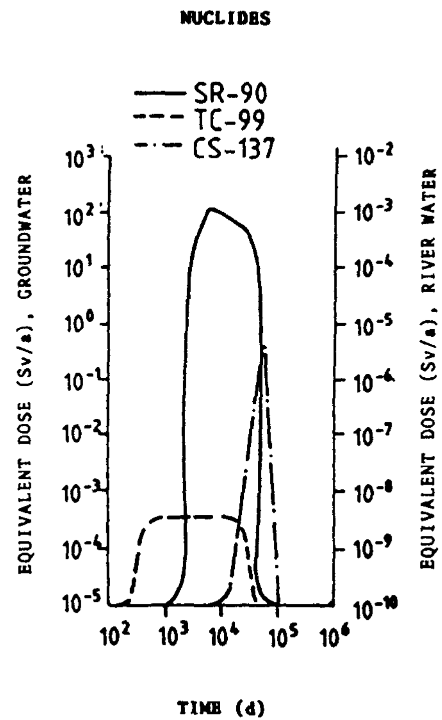

Fig. 1b:
Effective equivalent doses received by an adult as a result of the incorporation of drinking water prepared from groundwater and river water.