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MEASUREMENT OF MOISTURE MOTION UNDER A TEMPERATURE GRADIENT IN A CONCRETE FOR SNR-300 USING THERMAL NEUTRONS

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SUMMARY

For describing the bahaviour of the moisture in the concrete of the containment of SNR-300 in a hypothetical accident parameters were determined experimentally. The method is based on transmission of thermal neutrons through a plate of concrete. When a temperature of 170°C was applied at one end of the plate migration of moisture and evaporation took place. This could be observed by neutron radiography giving a gross picture of moisture migration. Furthermore the intensity of the transmitted neutron beam was measured with a neutron counter. From these values profiles of the change of moisture concentration could be obtained with a spatial resolution of few millimeters. The method used is entirely different from the conventional moisture meters which use fast neutrons. From the experimental data the mass transfer coefficient of vapour, the diffusion coefficient of vapour in concrete and the porosity of the concrete could be determined.

Introduction

The sodium-cooled fast-breeder reactor SNR-300 is equipped with several redundant and independent safety systems /1,2/. Nevertheless attention has to be paid to the hypothetical accident of a prompt critical excursion. For this case the safety concept of the SNR-300 assumes a partial destruction of fuel elements and the occurence of sodium vapor within the reactor tank. The mechanical properties of the reactor tank and the emergency core cooling system are so designed that they will prevent in general from any leakage of the primary system. Nevertheless a further safety barrier is built in form of containment system. The walls of the inner containment consist of concrete with a thickness of 1 - 2 m. Because of the heating of these walls in the case of a hypothetical leakage of the primary system an evaporation of water vapor results causing a rise of the pressure in the containment system. Therefore the behaviour of moisture in concrete under a temperature gradient was measured. The composition of 1 m^3 of the concrete investigated was (in kp)

cement HOZ 350L NW-HS Thyssen	260
water	160
sand 0-4 mm	686
basalt chippers 8-11 mm	891
gravel 16-31.5 mm	371
filler WDI type 45	80
MC-plast super 1.5%	
	2448

Method of measurement

For determination of the changes in moisture content transmission of thermal neutrons was used. This method is based on the high attenuation coefficient of hydrogen for slow neutrons. The transmitted neutrons were detected in two different ways. For obtaining an image of a greater area neutron radiography was chosen /3/. Neutron radiography was used yet by Reijonen and Pihlajavaara to determine the thickness of the carbonated layer of concrete /4/. In principle it is possible to get quantitative results from neutron radiographs /5/ by measuring the density of the film. But in the case of concrete the grainy structure makes it necessary to measure with the densitometer always exactly the same points to determine changes in neutron transmission. This is only very difficult obtainable. Because of this reason it was decided to measure simultaneously the intensity of the transmitted neutron beam with a counter. Based on preliminary tests a thickness of the concrete in the direction of the neutron beam of 5 cm was chosen. The reason is the heavy scattering of neutrons by hydrogen which has a negative influence on the measuring effect because of double scattering. For simulating infinite geometry the concrete plates of 50x50x5 cm^3 were isolated on the large faces with 5 mm PTFE being free of hydrogen for thermal isolation. On this a 5 mm thick Al-plate was pressed for balancing the pressure of the water vapor resulting from the heating of the block. The mounting of the block is shown in Figure 1. These plates were heated at one small side with a radiation heater. The temperature on the surface was held constant at 170°C and the temperature within the blocks was measured with thermocouples. Figure 2 shows the static temperature profile. Two of these blocks were put on little wagons and could be moved normal to the neutron beam emerging from the reactor.

The whole measuring assembly was built up at a beam hole of the 250 kW Triga Mark II reactor Vienna (Fig.3). The beam first passes through a 8 cm thick Bi-filter for reduction of the background of γ-rays in the beam. The collimator used was a conical one producing a "point source" of 17 mm diameter. For neutron radiography we used a 25 μm thick Gd-converter foil in direct contact with Osray TA T4 DW film from Agfa-Gevaert. High efficiency is obtained with the back screen technique where the neutrons first pass through the film. After their capture in Gd the resulting conversion electrons blacken the photographic film.

Alternatively the intensity of the transmitted neutron beam was measured using a BF_3-counter with a slit collimator. This collimator was 200 mm long with a slit of 2mm broadness and 2x8 mm heigth. For eliminating the deviations of the reactor power a monitor counter was used. This counter measured the intensity of neutrons reflected by a pyrolytic graphite crystal, which have a wavelength of 2 Angstroms in the first order reflex and the corresponding higher orders. The transmitted intensity was then reduced to constant counts in the monitor counter. The amount of changes in moisture content was then determined from the changes of neutron transmission of the concrete plate. Because of multiple scattering the mass attenuation coefficient of water could not be used for the evaluation. The calibration of the method was done by measuring the attenuation of the neutron beam caused by a series of water containers brought into the beam together with the concrete plate.

The method described using thermal neutrons is entirely different from the conventional fast neutron moisture measuring techniques. The main advantages of the presented method are the high spatial resolution and the possibility of determining changes in water content with good accuracy and without detailed knowledge of the composition of the material investigated. Attention must be paid to the fact whether substances with a high neutron attenuation coefficient migrate with the moisture, this was prooved by analysing water extracted from the concrete. The problems associated with fast neutron moisture meters are discussed in great detail by Mlitz and Neider /6/.

Experimental results

Figure 4 shows a typical neutron radiograph obtained 74 hours after begin of the heating. The heated surface is on the left side of the image. The exposure time was 13 minutes. This radiograph is a 1:1 copy of the original on Polaroid type 51 film. Dark areas are those of higher neutron transmission and therefore lower moisture content.

Typical results of the neutron intensity measurement are shown in Fig. 5 - 7. Figure 5 shows the lost moisture at a point 15 mm below heated surface as a function of time. According to figure 2 this point had an equilibrium temperature of about 130°C. It is interesting to note that an equilibrium of moisture content is not even reached after a time of 200 hours. For other points farer away from the heated surface the moisture content first increased with time and later on decreased. On figures 6 and 7 profiles of moisture losses for different times are drawn. The time t_o is the measuring time beginning from heating of the first point at the heated surface. The time needed to measure one point was 7 minutes, so the profiles shown are not exactly profiles of the same time. But as simple interpolation shows the deviations are not big. The zero-line corresponds to the initial moisture distribution before heating. The movement of moisture within the concrete plate is as expected. Here the deeper regions where the water content rises can easily be seen. The relative minimum on the last diagram at a depth of 20 mm corresponds to the inhomogeneity of the concrete.

Evaluation of parameters

Preliminary calculations showed that the temperature gradient normal to the large face of the concrete plate is small enough to be neglected. Therefore the further calculations were performed using a onedimensional model. It only had to be corrected for temperature losses normal to the plate. For the diffusion equation holds

$$\frac{\partial \rho}{\partial t} = D \frac{\partial^2 \rho}{\partial x^2} + q$$

$\rho(x,t)$	vapour concentration
D . . .	vapour diffusion coefficient
x,t . .	distance from heated surface, time
q(x,t)	source term
$q \cdot \psi$.	rate of evaporation or condensation
ψ . . .	porosity (fraction of volume of pores)

q describes the amount of moisture in a volume element which can be brought into vapor phase for thermal equilibrium. When condensation occurs q changes sign.

The boundary condition is a mass transfer law

$$\frac{\partial m}{\partial t} = \beta(\varrho_s - \varrho_e)$$

β . . . mass transfer coefficient
ϱ_s . . . vapour density within surface of concrete
ϱ_e . . . vapour density in surrounding space

The initial condition is simply a state of equilibrium according to the initial temperature of the concrete plate.

The equation of thermal conductivity is

$$\frac{\partial T}{\partial t} = \frac{\lambda}{\varrho c}\frac{\partial^2 T}{\partial x^2} + \frac{r_w}{\varrho c}\cdot q - 2\frac{\gamma}{\varrho c}(T - T_0)$$

$T(x,t)$ temperature of concrete
λ . . thermal conductivity of concrete
ϱ . . density of concrete
c . . specific heat of concrete
r_w . heat of evaporation of water
γ . . heat transfer coefficient
T_o . temperature at surface of assembly

The last term of the equation corrects for temperature losses normal to the concrete plate. The boundary conditions here are a fixed temperature at the hot end of the plate and a heat transfer law at the cold end. The initial temperature is room temperature. Discreting space and time the above equations were solved on a numerical computer using a difference method (Crank-Nicolson /7/). Main emphasis was put on the evaporation rate on the hot end of the concrete plate. Therefore the integrated loss of moisture as a function of time was calculated from the experimental data. The figures used in evaluation were then the loss of moisture per unit of time (evaporation rate). From the evaporation rates at low times the mass transition coefficient of vapour was determined to be 0.15 m/h. The determination of the diffusion coefficient D and the porosity ψ was then performed by solving the above set of equations with a given pair of D and ψ and changing these values up to an optimum fit of the experimental evaporation rate. By this way D = 0.0075 m^2/h and $\psi = 0.3$ were obtained. These values are very well within the expected range. For D confer for example /8/. The accuracy of the values obtained will be discussed in more detail later on.

These results are one basis for quantitative statements necessary for determining the behaviour of the reactor containment in a hypothetical accident. The material constants determined in this work are used futher on in theoretical models of the situation of an accident.

References

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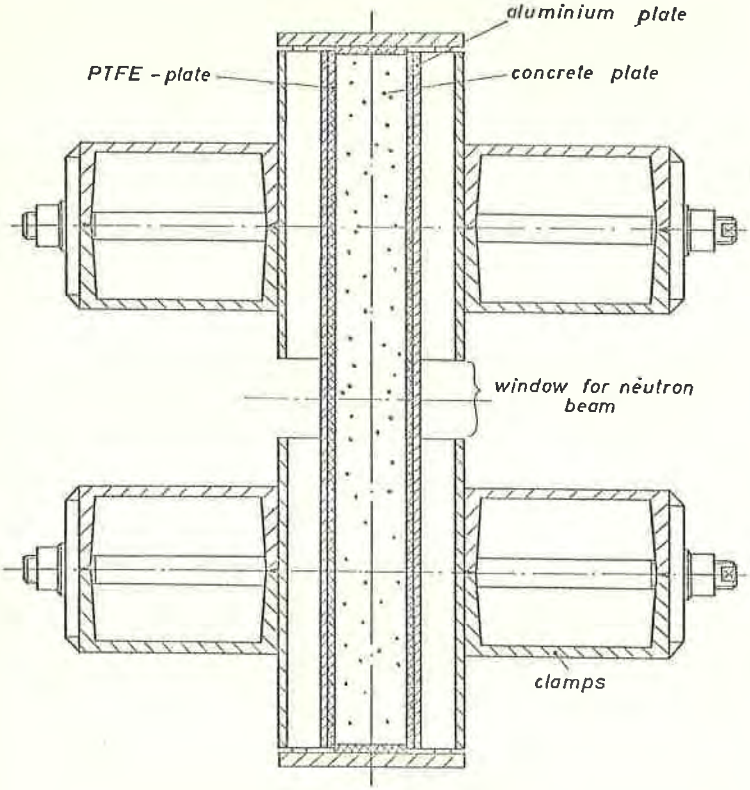

Fig.1: Mounting of the concrete plate.

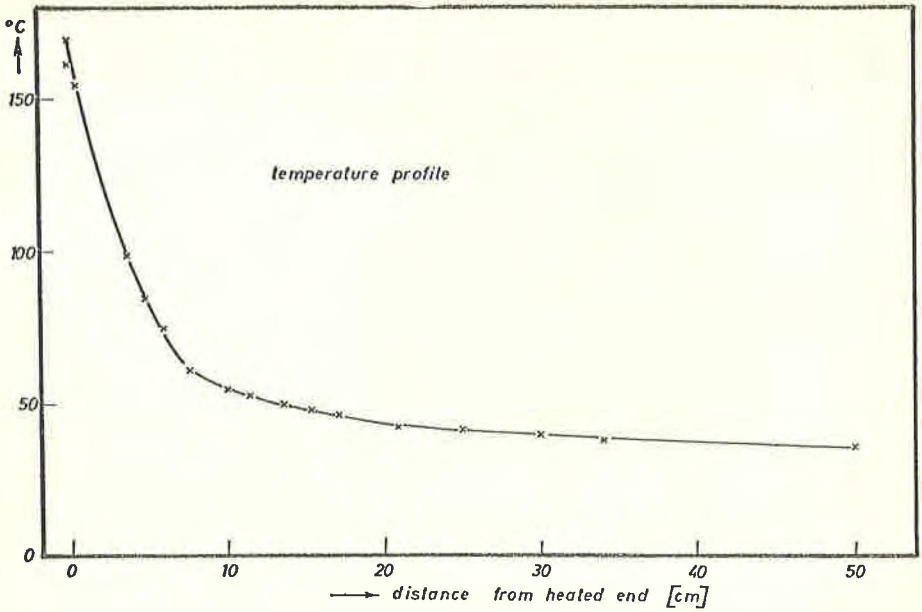

Fig.2: Temperature profile in concrete plate in equilibrium.

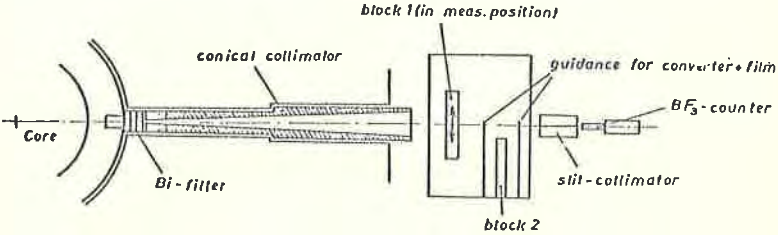

Fig.3: Arrangement at reactor.

Fig.4: Neutron radiograph obtained 74 hours after begin of heating. Dark areas have lower moisture content.

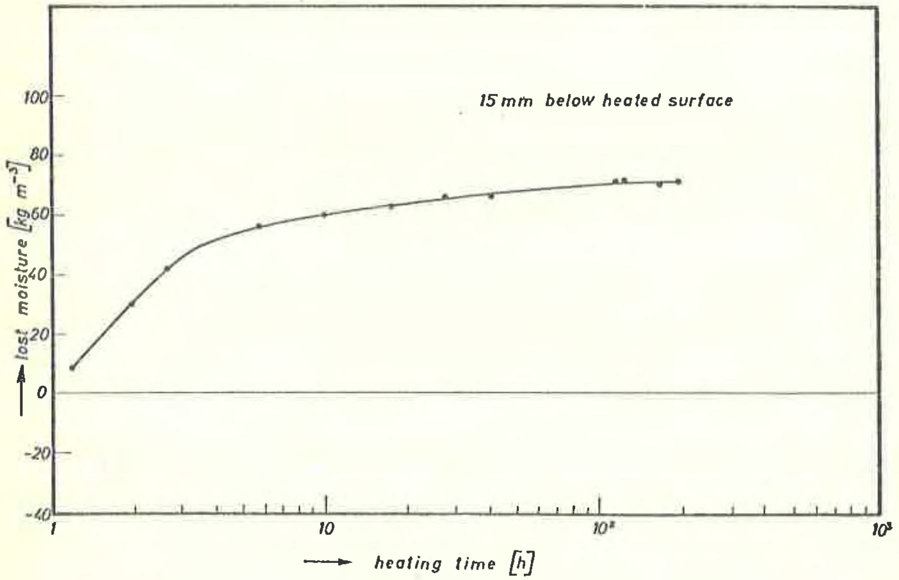

Fig.5: Loss of moisture content with time.

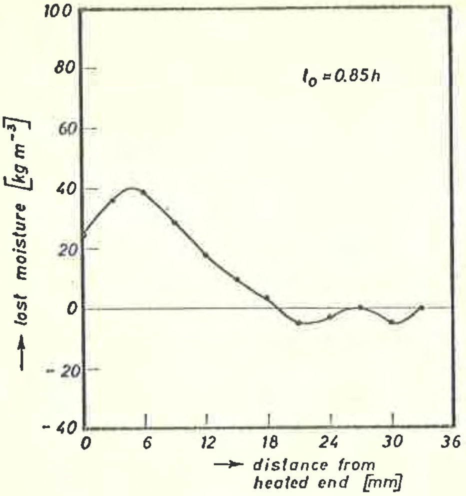

Fig.6: Profile of change of moisture concentration for low heating time.

Fig.7: Like fig.6 for a heating time of 194.5 hours.