EXPERIMENTAL LOOP IN THE NUCLEAR TRAINING REACTOR BUDAPEST

By

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Introduction

Some years ago, on the basis of earlier investigations and planning experiences [1, 2] urged by recurrent demand we decided on constructing an experimental loop in the nuclear reactor of the University in co-operation with the staff of MEI*. After the first studies [3, 4, 5] and multilateral consultations, the final plan of the experimental loop was completed [6].

NAEC** and CHEMIMAS*** encouraged us, CHEMIMAS also financially, to construct the experimental loop because our interest in the construction of water treatment equipment within the Comecon necessitated in Hungary to study the processes in the primary and secondary cooling circuits of WWER type pressurized water reactors like the one being under construction in Paks Nuclear Power Plant. These studies can conveniently be made in the experimental loop suitable for carrying out irradiations within the reactor. This way the changes, and the kinetics and mechanism of radiochemical processes taking place as a result of complex (neutron + gamma) radiation in the liquids and in compounds dissolved in the liquids can be studied.

The experimental loop and its function

The experimental loop (Fig. 1) built on the basis of the final plan had to meet the following requirements:

— liquid flow at temperatures of 20 to 300 °C in the loop,

— the possibility of producing variable pressures in the loop up to 150 bars,

— feed of salts into the water circuit,

— gathering of gaseous products,

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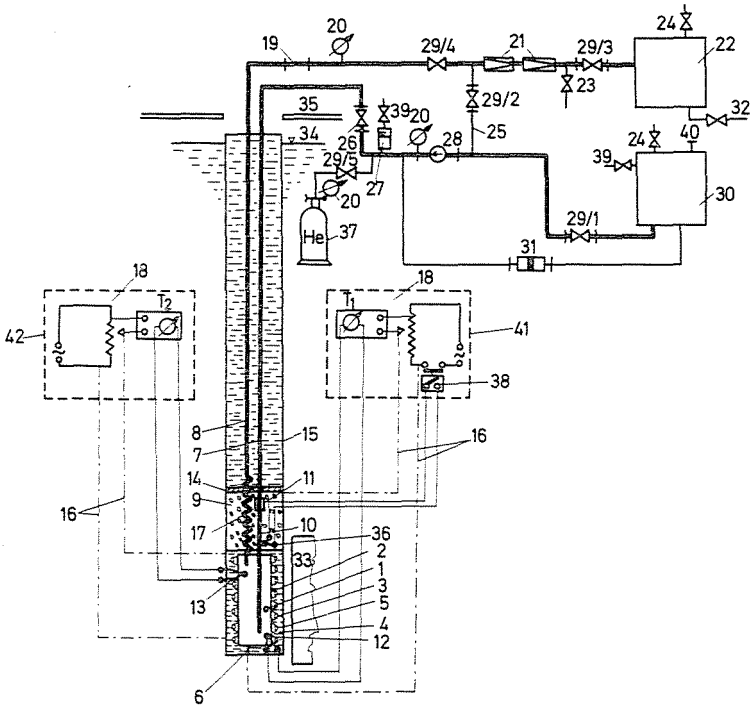

Fig. 1. 1 — irradiation rig; 2 — enamel insulation; 3 — electrical heating filament; 4 — thermal insulation; 5 — protective shield; 6 — electrical heating connection; 7 — solution inlet pipe; 8 — solution outlet pipe; 9 — aluminiumoxide powder; 10 — heated pipe section; 11 — heating current connection; 12 — thermocouple for measuring the temperature of the inlet solution; 13 — thermocouple for measuring the temperature of the outlet solution; 14 — cover; 15 — outer protective shield; 16 — electrical cable; 17 — heated pipe coil; 18 — drop hammer thermoregulator; 19 — pipe insertion; 20 — pressure gauge; 21 — pressure reducing valve; 22 — sampling vessel; 23 — capillar; 24 — volume flow meter; 25 — by-pass; 26 — throttle; 27 — trimming tank; 28 — pump; 29 — shut-off valves; 30— preparatory vessel; 31 — overpressure; 32 — mixing valve; 33 — active zone; 34 — water level of the reactor tank; 35 — top of the reactor tank; 36 — thermocouple for overheating protection; 37 — He-cylinder; 38 — safety switch; 39 — He inlet connection; 40 — priming valve; 41 — preheater; 42 — temperature control unit

— measurement of pH and conductivity of liquids,

— hermetic sampling,

— suitable automatic control system and safety valves for the operation of the loop,

— suitable radiation shielding for the plant,

— irradiation of the liquids at a dose rate as high as possible,

— versatile set-up to permit testing the corrosion resistance of different structural materials with minor modification.

Dosimetric conditions in the experimental loop environment

In radiolytic tests, the sample is exposed to radiation the effect of which is to be tested while (or thereafter) the change of one of the important parameters of the material is investigated as a function of the dose [7]. The radiation effect can only be detected above a certain threshold dose level. Therefore we want to ensure a dose rate as high as possible.

Since, for safety reasons, the high-pressure loop could not be built in the core, we wanted to mount it outside the core next to graphite block No. A5 (Fig. 2.) nearest to the core. The dose conditions for a reactor power of 10 kW prevailing were measured here by means of chemical dosimeters and activation detectors [8]. An external vertical channel ('KFCS') was built in for this purpose at the place mentioned.

The results of the chemical dosimeters are shown in Table 1.

Table 1
Results obtained by chemical dosimetry

Method	dose rate [kGy/h]
Fricke-dosimeter [9]	4.9
Chlorobenzene-dosimeter [10]	5.3
Average:	5.1

Note:
1) Thermal neutrons have no effect on chemical dosimeters
2) Deviations measured longitudinally in the channel are below 10%; therefore, only the results measured in the centre of the channel have been specified.

Using the activation detectors, the neutron spectrum was divided in five groups on the basis of neutron energy. The neutron spectrum of the WWR-S-type LWR was used to the data evaluation.

First the neutron group flux values were measured in the different energy groups in the KFCS channel. Then, the average energy was calculated in the different energy groups, and finally, in the knowledge of these, the kerma dose rate was determined using the neutron flux to dose rate conversion factors for water in the case of strong diluted aqueous solutions:

$$\dot{D}_k(\bar{E}_i) = d_{k,i}\Phi_i \tag{1}$$

where $\bar{E}_i$ average energy of neutron group i
$d_{k,i}$ flux to dose rate conversion factor belonging to $\bar{E}_i$
Φ_i flux in neutron group i

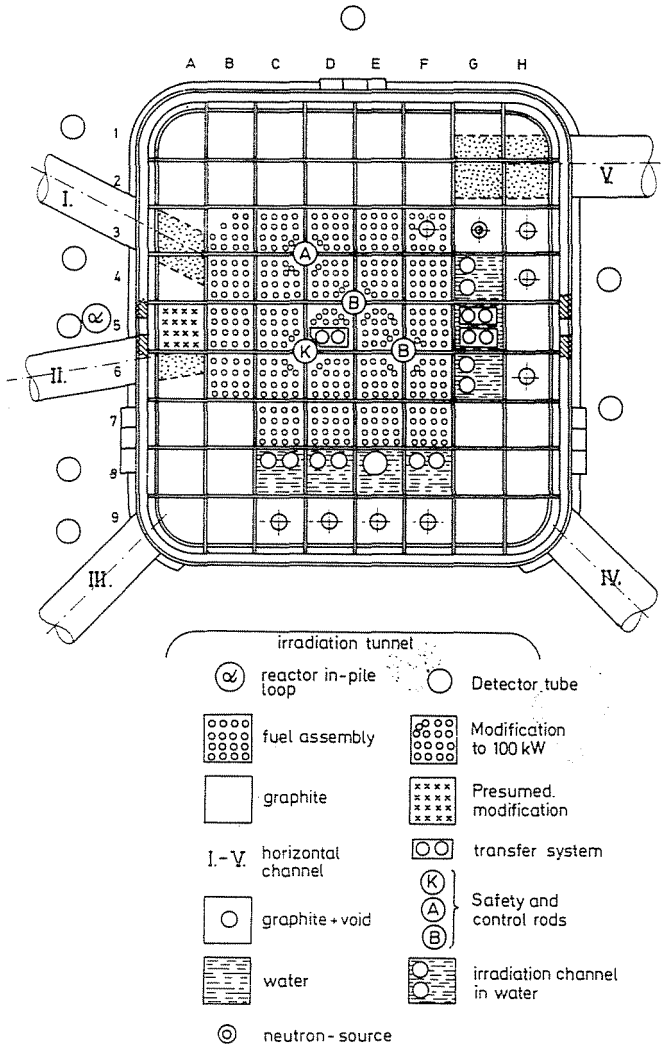

Fig. 2. Cross section of the reactor core with the presumed modification

The total dose rate due to neutrons can be obtained by the sum of the above values for all neutron groups:

$$\dot{D} = \sum_i \dot{D}_k(\bar{E}_i) \tag{2}$$

The numerical values of d_k conversion factors for water as a function of neutron energy are tabulated in Table 2.

Table 2
Conversion factors for water

Neutron energy MeV	d_k $[10^{-16}Gy \cdot m^2]$
0.01	1.04
0.05	4.23
0.1	6.95
0.5	18.0
0.7	20.5
1.0	27.8
2.0	33.0
5.0	46.5
10	54.4
14	65.0

With the activation detectors, measurements were made in 6 points along the channel in the range of 60 to 235 mm from its bottom. The results of these measurements for a reactor power of 10 kW in the five neutron energy groups are shown in Table 3 and Fig. 3. The tabulated data suggest that:

— the dose rates in each energy group and thus also the total dose rate change only slightly (by max. 10%) over the length of 190 mm investigated (similarly to the results obtained by chemical dosimeters),

Table 3
Neutron dose rate values in kGy/h

Neutron energy groups	Position No.					
	1	2	3	4	5	6
	Position in KFCS mm					
	60	95	130	165	200	235
Thermal (E < 0.465 eV)	1.74	1.89	1.83	1.91	1.87	1.80
0.465 eV < E < 10 keV	0.43	0.47	0.53	0.52	0.46	0.48
10 keV < E < 1 MeV	0.58	0.63	0.61	0.64	0.62	0.60
1 MeV < E < 3 MeV	1.27	1.41	1.28	1.46	1.40	1.42
E > 3 MeV	0.48	0.53	0.56	0.57	0.55	0.49
Subtotal E > 10 keV	2.33	2.57	2.45	2.67	2.57	2.51
E > 1 MeV	1.75	1.94	1.84	2.03	1.95	1.91
Total dose rate	4.50	4.93	4.81	5.10	4.90	4.79

— the total neutron dose rate amounts to rounded 4.8 kGy/h on the average over the full length. In positions 3 and 4 where also chemical dosimeters were used for the measurements the dose rate amounted to 4.81 kGy/h and 5.10 kGy/h, respectively. From among neutrons, about

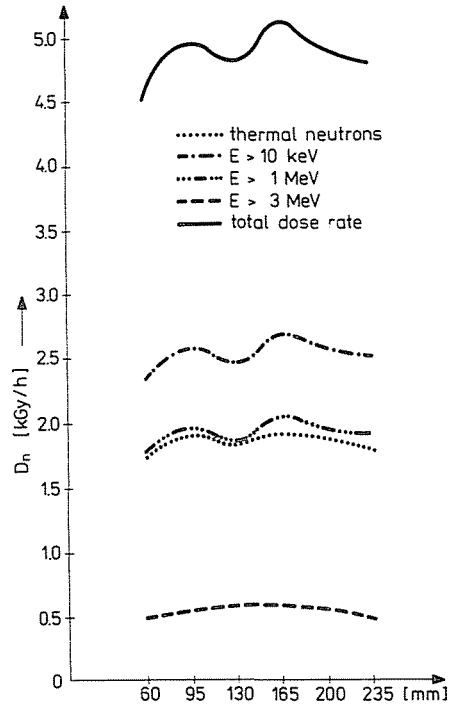

Fig. 3. Neutron dose rate as a function of neutron-energy and detector position inside the KFCS at a reactor power of 10 kW

1.9 kGy/h (i.e. round 40%) results from thermal neutrons and the contribution by neutrons of an energy above 1 MeV is also about 40% while by neutrons of $E_n = 0.465$ eV to 10 keV the contribution to the dose rate is about 10%,

— within the area investigated, the average dose rate resulting from intermediate and fast neutrons (i.e. from those of $E_n > 10$ keV) is about 2.5 kGy/h that is about 50% of the total neutron dose rate.

A comparison of the results obtained by activation detectors and CaF_2 TL dosimeters [15] shows that the neutron dose rate and gamma dose rate is approximately identical in the KFCS. It can also be stated that the gamma dose rate is 6.3 kGy/h in the channel tested (about 55% of total neutron plus gamma dose rate).

The possibilities to increase the dose rate [8]

In order to obtain results applicable also to plant conditions, a minimum dose rate of 18 kGy/h due to fast neutrons is required for the tests planned. Under the conditions outlined above, this dose rate is only 2.5 kGy/h i.e. only 1/7 as compared with that required.

Two possibilities have offered themselves to increase the dose rate such as:

a) modification of the active core to increase the neutron flux density in the external vertical channel and to harden the spectrum simultaneously,

b) increase of the reactor power to minimum 7fold i.e. to 70 kW.

Ad a):

The active core can be modified by replacing the graphite element A5 with a fuel assembly to reduce the distance between the active core and the external vertical channel.

As a result of such a modification, the total dose rate resulting from neutrons would increase considerably—to about 2.6fold—at the place of the external vertical channel the average dose rate being thus about 13.5 kGy/h.

Within the increased total neutron dose, the ratio of dose rate resulting from fast neutrons increases considerably due to spectrum hardening. The dose rate resulting from neutrons of an energy above 10 keV which are of special interest from the point of view of our investigations *can be increased to round 4.3-fold* without increasing the reactor power. This means that the fast neutron dose rate of 18 kGy/h required for the investigations can be ensured at a reactor power of only 17 kW in case of the modifications mentioned. The expectable changes are indicated in Fig. 4 and Table 4.

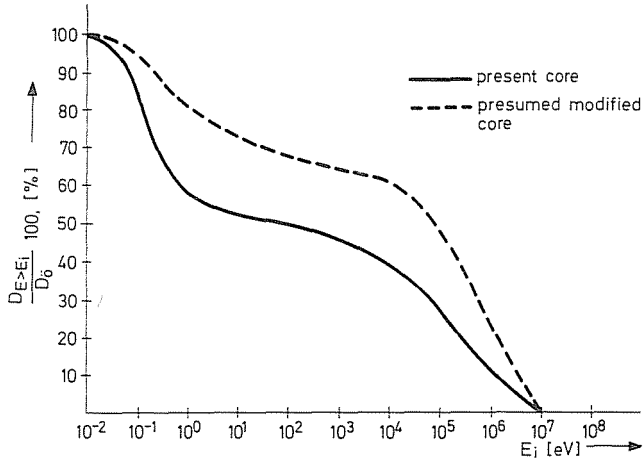

Fig. 4. Distribution function of neutron dose rates for the present (10 kW) and the presumed modified cores ($D_{\tilde{0}} = D_{\text{total}}$)

Ad b):

The reactor was being under reconstruction when this study was made. As a result, the reactor power could be increased from 10 kW to 100 kW which, considering what was said earlier, ensured the required dose rate.

Table 4

Relative distribution of dose rate depending on neutron energy resulting from neutrons for unchanged and presumptive modified active core configuration ($\dot{D}_{E>E_i}/\dot{D}_{\text{total}}$) *in* %

Lower energy limit	Unchanged core	Modified core (presumption)
0	100.0	100.0
0.465 eV	62.0	84.6
10 keV	52.1	72.2
1 MeV	39.3	61.2
3 MeV	10.9	24.8
~10 MeV	0	0

The modification of the core described under point a) may be of interest even in case of increased reactor power because of spectrum hardening and the required lower power. Methods a) and b) may be used in combination for the radiolytic tests.

Tests in the experimental loop

Earlier theoretical investigations were made on the damages of ion exchange resin due to radiation [1, 2]. Since synthetic ion exchange resins will be damaged only if exposed to a total dose of 10^5 to 10^6 Gy, we concluded that such a dose could be ensured with the dynamic method (under our circumstances) within reasonable time only if the total neutron flux had been minimum $10^{16}\ m^{-2}\ s^{-1}$ in our reactor. Therefore, we did not even start the radiation damage tests at that time. However, we also concluded that the ion exchange resin could not be damaged at all in the technological process of nuclear power plants and that it was the reprocessing process of spent fuel elements alone where the resin might be damaged.

In co-operation with MEI, we intend to run the following investigations:

— The additives in water circulating in the heat trasfer system reduce the corrosion of the structural materials. Therefore, Soviet research workers suggested using the complexing agents successfully applied in the water circuit of conventional power plants also in the water circuit of nuclear power plants [11, 12, 13]. A precondition for this is to know the behaviour of these materials when exposed to heat and radiation and to know what happens to the complex compounds produced of the corrosion products of steel—first of all to Fe/III/EDTA (EDTA = ethylenediamine-tetracidic acid)—under similar circumstances. (This has already been investigated with ampoule tests in the gamma-radiation field [14]).

— It is also important to investigate how the magnetite protective layer produced by the decomposition of these materials is built up and to determine the maximum protection by this layer.

In the possesion of the results of our investigation methods can be worked out by means of which the concentration of the corrosion products in the cooling medium and the corrosion of the structure material can be reduced. In certain places austenite steel might be replaced with perlite steel.

Summary

The in-pile loop built into the Nuclear Training Reactor of the Technical University Budapest is a common design carried out together with the specialists of the Moscow Energetic Institute (MEI). This experimental facility is serving for thermoradiolytic investigations of irradiated solutions under conditions of 20—300 °C temperature and max. 150 bar pressure. Therefore, the results of such experiments can provide valuable informations on the kinetics and mechanisms of chemical processes occurring in the primary and secondary circuits of WWER-type power reactors.

References

1. Csom, Gy., Élő, S., Kocsis, E., Lévai, F., Virágh, E.: Study on resistance to radiation of ion exchange materials.—BME-EAR-3/1969. Budapest.*
2. Kocsis, E.: Changes in ion exchange resins as a result of external radiation exposure.—BME-EAR-39/1975. Budapest.*
3. Tevlin, Sz. A., Milajev, A. I.: Preliminary Study for the Reactor Loop to be Constructed in the Training Reactor of BME. (TRAVOR-UR) Moscow, 1975 (manuscript).
4. Kocsis, E.: Study—a Plan of the high-pressure high-temperature reactor loop to be constructed in the Training Reactor of BME.—BME-TR-38/1975, Budapest.*
5. Csom, Gy., Kocsis, E., Farkas, D., Angyal, J., Szabó, M.: The HP-FT reactor loop to be constructed in the Training Reactor of BME.—Energia és Atomtechnika *29*, 412 (1976).
6. Csom, Gy, Szücs, I., Angyal, J., Szabó, M., Kotsy, F., Kocsis, E., Porkoláb, S., Virágh, E.: Construction and putting into service of an experimental loop suited for materials testing in a mixed radiation area at high pressure and high temperature.—Specifications, Drawings, Permit Documentation, Description, Safety Analysis (BME-TR-72/1977) Budapest.*
7. Verescsinszky, I. V., Pikajev, A. K.: Initiation into radiolysis.—Műszaki Könyvkiadó, Budapest 1967 (in Hungarian).
8. Kocsis, E., Csom, Gy., Szondi, E. J., Zsolnay, É. M., Szücs, I.: Ampoule experiments to investigate the radiolysis of solutions of complexing agents and the preventive dosimetry (BME-TR-71/1977) Budapest.*
9. Fricke, H.: Phil. Mag. *7*, 729 (1929).
10. Dvornik, I., Lee, U., Ranagajee, F.: 'Food Irradiation'—IAEA Vienna *81* (1966).
11. Margulova, T. H.: Primenenie kompleksonov v teploenergetike. Izd. Energija, Moscow 1973.
12. Milajev A. I., Tevlin S. A.: At. Energ. *33*, 673 (1972).
13. Lebegyev, F. A.: Investigation of the radiolysis of complexing agents and iron complexonates. Doctor's Thesis, MEI, 1969.
14. Weber, M.: Thesis, Budapest, 1976 and Weber, M., Földiák, G., Kocsis, E.: Radiolysis of aqueous iron (III) EDTA systems Acta Chim. Acad. Sci. Hung. *97*, 255 (1978).
15. Virágh, E.: Private communication.

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