MEASUREMENT OF GAMMA FIELD PARAMETERS IN CORE WITH LEU FUEL IRT-4M USING TL DETECTORS

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ABSTRACT

Thermoluminescent dosimeters represent very useful tool for gamma fields parameters measurements at nuclear research reactors, especially at zero power ones. ^{7}LiF:Mg,Ti and ^{7}LiF:Mg,Cu,P type TL dosimeters enable determination of only gamma component in mixed neutron – gamma field. At VR-1 reactor operated within the Faculty of Nuclear Sciences and Physical Engineering at the Czech Technical University in Prague the integral characteristics of gamma rays field were investigated, especially its spatial distribution and time behaviour, i.e. the non-saturated delayed gamma ray emission influence. Measured spatial distributions were compared with monte carlo code MCNP5 calculations. Although MCNP cannot generate delayed gamma rays from fission, the relative gamma dose rate distribution is within ± 15% with measured values. The experiments were carried out with core configuration C1 consisting of LEU fuel IRT-4M (19.7 %).

Introduction

The in-reactor gamma ray physics is rather complex because there are several sources of gamma radiation, which are of different importance at different regions of the reactor. Of the greatest importance are gamma rays from fission (prompt and delayed), neutron capture in fuel or structural materials (prompt and activation) and from inelastic neutron interactions.

Employing LiF type thermoluminescent dosimeters (TLDs) enriched on Li-7 enables measurement of only gamma component of mixed neutron – gamma field. LiF type dosimeters are widely used in many dosimetric applications and their characteristics are well-known. They seem to be a proper tool for gamma fields parameters measurement on zero power reactors because their useful dosimetric range corresponds to doses occurring on them.

Due to the nature of TL dosimeters only integral gamma field parameters could be measured. This involves spatial distribution of gamma dose rates in in- and ex-core regions and time behaviour of gamma radiation source. However, such knowledge is valuable for many applications especially due to its connection to gamma heating phenomenon. Although totally gamma heating represents solely a small part of total one, in certain regions it is the main heating contributor. Thus knowledge of gamma field parameters is important for such applications such as proper cooling design or thermal stresses determination.

Reactor VR-1 at DNR, Prague

VR-1 is a school light water zero power pool type reactor. The core consists of three various tubular fuel assembly types: four-, six- and eight-tube fuel assemblies. Enrichment on U-235 amounts 19.7%. Reactor power is indicated in impulses, 1E8 being the nominal one what roughly corresponds to 1 kW. All TL investigations were carried out in core configuration C1 (fig. 1).

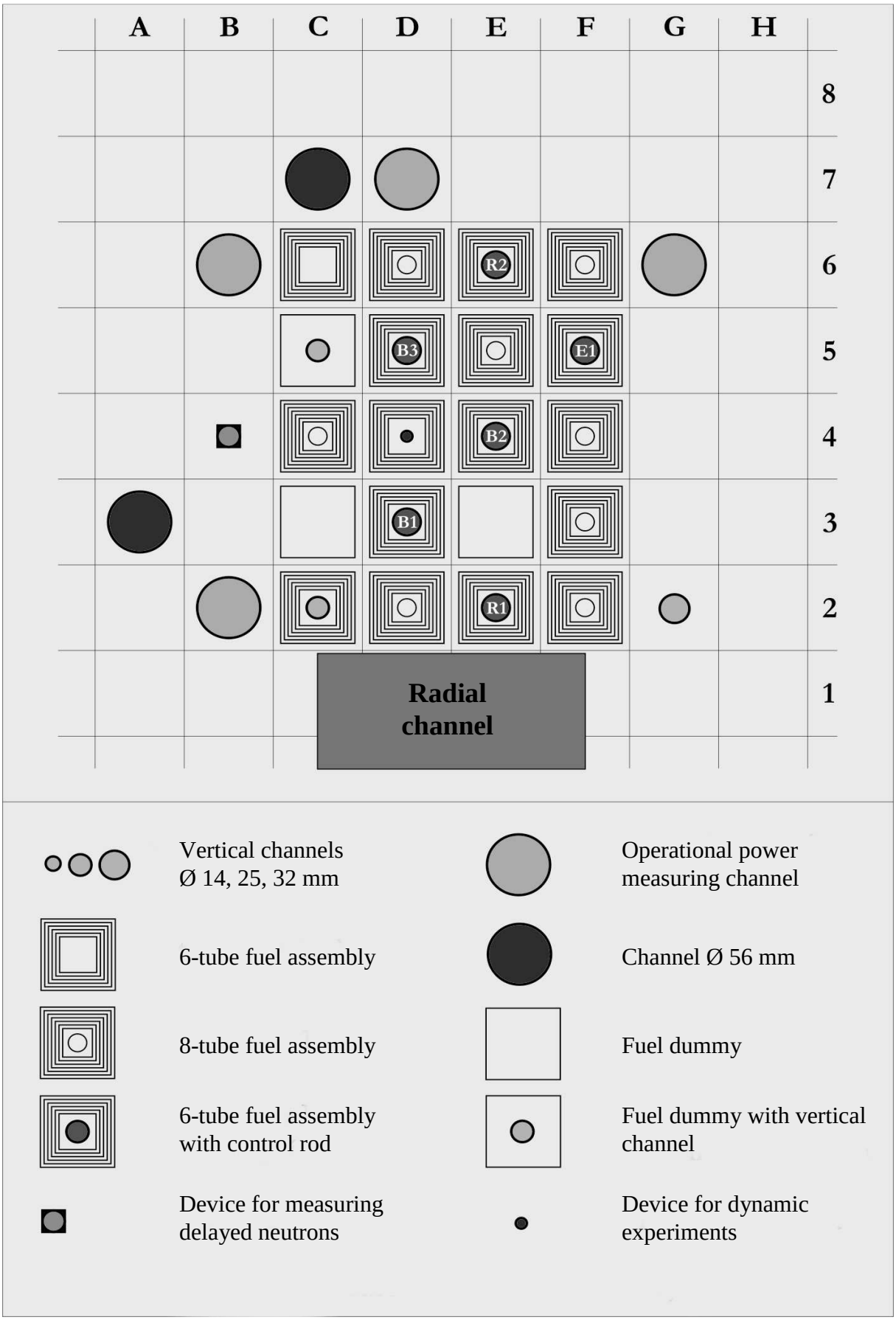

Figure 1 Core configuration C1 of the VR-1 reactor. Control rods B1, B2, B3 and E1 were in their top positions (i.e. above the core)

TL method

Thermoluminescence is defined as „the thermally stimulated emission of light following the previous absorption of energy from radiation“.

When a TL dosimeter is irradiated, a part of incident ionising radiation is deposited in TLD by creating electron/holes pairs which could be trapped at various levels. If the trap is depth enough (i.e. the energy difference between conduction band and the trap) then trapped charge carriers stay until their escape probability is increased somehow. One way how to bring the amount of energy needed to release traps is heating of TLD. Through the heating process charge carriers return into stable state by recombination of electron/holes pairs. This leads to release of certain amount of energy which could also take place by emission of visible light. Its quantity measured via photomultiplier tube is proportional to radiation dose.

For in-reactor measurements only such TL detector types are proper which enable to distinguish between neutron and gamma doses. This is the case of LiF type dosimeters which are usually provided with three different lithium isotopes ratios: enhanced on Li-6, natural composition of Li-6 and Li-7 and enhanced on Li-7 (99.96-99.99% Li-7, 0.01-0.04% Li-6). Due to high neutron cross section of Li-6 especially in thermal region the first two types are very sensitive to neutrons; on the other hand, Li-7 due to its very small neutron cross section is almost insensitive to thermal neutrons.

Within current investigations two polish ^{7}LiF type TL dosimeters were used: MCP-7 pellets (Ø 4.5 mm and 0.9 mm height) represent ^{7}LiF:Mg,Cu,P material while MTS-7 chips (3.2 x 3.2 x 0.9 mm^{3}) ^{7}LiF:Mg,Ti one. Applied TL cycle is summarized for both types in table 1.

TLD type	Pre-Irradiation Annealing	Read out
MTS-7	400°C for 1 hour, then slow cooling in oven to ambient temperature	5°C/s up to 400°C
MCP-7	240°C for 10 min, then fast cooling on metal plate.	preheat 5s at 150°C, then 5°C/s up to 245°C

Tab. 1 TL cycle for MTS-7 and MCP-7 dosimetres

The corresponding glow curves are shown in fig. 2. Glow curve of MCP-7 possesses well separated main dosimetric peak, thus for dose determination both peak height and peak area were used. In case of MTS-7 only 210°C peak height was used. The read-out procedure was performed in commercial TL-reader RA’94.

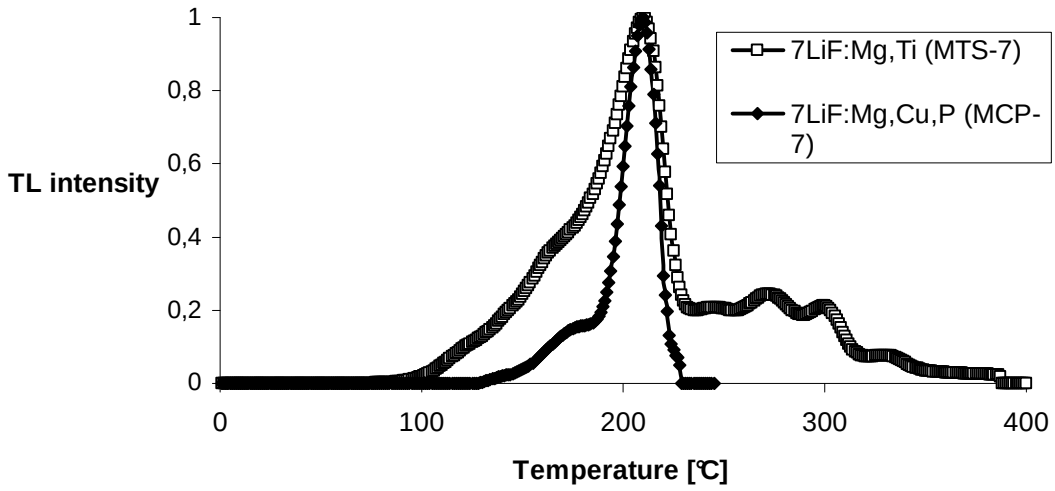

Figure 2 Glow curves of MTS-7 and MCP-7. Normalized to the main dosimetric peak height.

Reactor irradiation

Gamma dose distribution in core configuration C1 was determined in several positions of the core vertical mid-plane and in radial channel. Moreover axial distribution of gamma dose rate in fuel assembly at C2 position was measured. For irradiations in the core vertical mid-plane the reactor power of 3E6 was chosen as an optimal one for simultaneous irradiation of both TLDs types (according to producer the MCP-7 is ca. 30 times more sensitive than MTS-7); in case of radial channel (at the distance of 75 cm from the core boundary) it was 1E7 for 20 minutes; finally in case of axial distribution the irradiation was performed at 3E6 power level for 10 minutes to minimise the error arising from inserting and removal of the holder with TLDs into and from the core. In all cases MCP-7 and MTS-7 detectors were irradiated simultaneously at the same positions.

TL method enables to some degree to examine the time behaviour of gamma source in the reactor. After reactor reaches desired power the gamma ray emission is still growing until it achieves its saturation state. Of course, this is caused by gamma rays from fission products decay. Within current investigations such measurements were carried out in the fuel assembly at C2 position, in fuel dummy at C5 and in reflector channel at G2. TLDs were irradiated for 2 minutes at various times after reaching given power. The early phase of gradual saturation is shown in fig. 4. Presented time values correspond to the middle of 2 minutes irradiation interval.

Computational verification

As the exact power of the VR-1 reactor is known in a relative way only, i.e. in impulses, also the computational verification was done in a relative way only. Computations were carried out in MCNP5 with the utilization of detailed VR-1 model which is standardly used at DNR for neutronic calculations.

Calculations were carried out in coupled neutron photon mode N P which assumes locally deposition of secondary electrons. Number of neutron histories used for normalizing tallies

reached to 5 000 000 (50 inactive and 200 active cycles with 25 000 neutrons in each generation).

MCNP cannot generate delayed gamma rays from fission. This fact introduces some error in computed results even if only relative distribution is to be determined; it is caused by different relative importance of delayed gamma source in various core locations. Thus only crude agreement could be expected from comparison of MCNP and TLD results.

MCNP normalized its results to MeV/gram per fission neutron units. For comparison purposes MCNP results were renormalized to TLD values at H2 position; i.e. to MCP-7 H2 value in case of comparison with MCP-7 detectors and to MTS-7 H2 value in case of comparison with MTS-7 ones. Ratios of renormalized MCNP results to those obtained using TLDs are given in table 2.

Results

Figure 3 shows the axial gamma dose rate distribution in fuel at C2 position obtained both using TL method and MCNP5. As there was no systematic difference found between MCP-7 and MTS-7 values, an average of both is presented. The distribution consists of two parts: in the core it follows the sine function; in the reflector the dose decrease should be approximated by exponential curve.

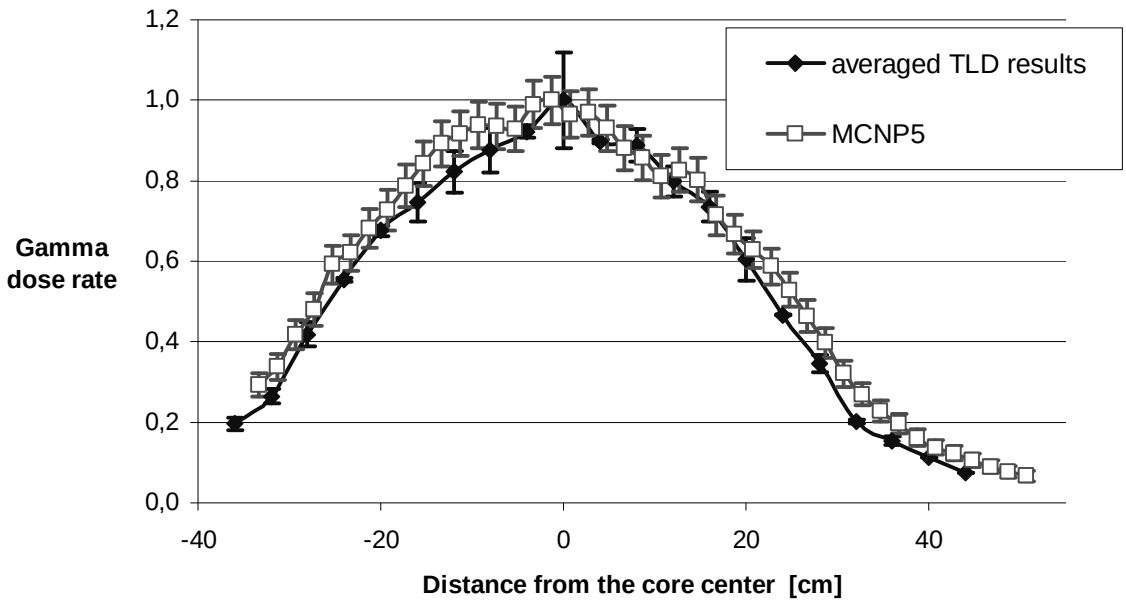

Figure 3 Axial gamma dose rate distribution in fuel at C2 position

Table 2 shows the comparison of results obtained with MCP-7 and MTS-7 respectively. It comprises results from reflector irradiations (positions G2, G3, G4, G5 and H2), axial distribution measurement and radial channel measurement. The discrepancies in measured dose values were assessed using MCP-7/MTS-7 ratio.

Irradiation	Dose ratio (MCP-7/MTS-7)
VR-1 reflector	0,93 ± 0,11
VR-1 axial distribution	1,05 ± 0,18
VR-1 radial channel	0,95 ± 0,12

Tab. 2 MCP-7 /MTS-7 ratio for various irradiations at VR-1. Uncertainties are on 3σ level

In table 3 the comparison of measured and computed relative distributions in vertical core mid-plane and in radial channel is made. It is seen that the relative distribution computed in MCNP5 differs from those obtained from measurements with both MTS-7 and MCP-7 by less than 15%. In most cases the differences are within the 3σ uncertainty interval.

Core position	Calculated gamma dose (MeV/g/fiss. neutron)	St. dev. (3σ)	MCNP/MCP-7	St. dev. (3σ)	MCNP/MTS-7	St. dev. (3σ)
C5	1.60E-05	8.15E-07	**0.91**	0.10	**1.03**	0.09
C2	1.28E-05	7.63E-07	**0.86**	0.05	**1.04**	0.06
G2	7.57E-06	4.52E-07	**1.08**	0.08	**1.00**	0.08
G3	1.02E-05	5.43E-07	**0.91**	0.11	**0.90**	0.05
G4	1.16E-05	5.83E-07	**1.00**	0.10	**0.94**	0.05
G5	1.06E-05	5.58E-07	**1.01**	0.10	**0.91**	0.11
H2	4.47E-06	3.58E-07	**1.00**	0.09	**1.00**	0.13
Radial channel	1.40E-07	1.93E-08	**1.03**	0.16	**1.01**	0.16

Tab. 3 Comparison of calculated and measured gamma dose rate values.

Figure 4 illustrates time behaviour of in-reactor gamma ray field. Gradual saturation of delayed gamma emission is well observable in fuel assembly at C2 position. Dose rate increase between measurements carried out ca. 2 and 25 minutes after reaching given power achieves ca. 20 %. In the dummy was this effect slighter and in reflector channel the time behaviour of gamma emission was within statistical uncertainties.

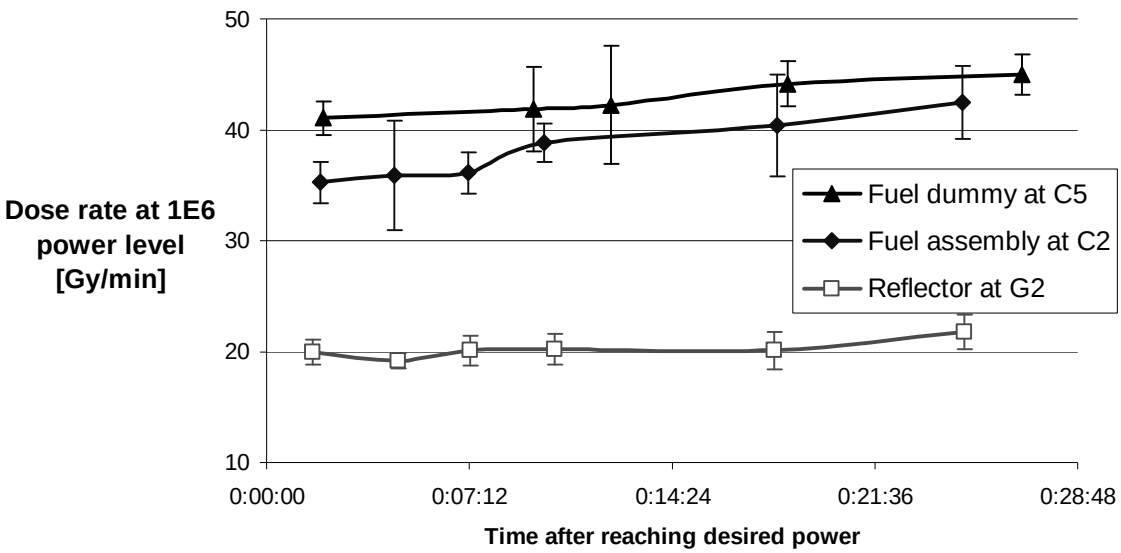

Figure 4 Gradual saturation of delayed gamma emission in fuel assembly (MTS-7), fuel dummy (MCP-7) and in reflector channel (MCP-7).

Discussion, conclusion

At the VR-1 reactor the gamma dose rate distribution in core configuration C1 was measured using two types of TLD detectors. Results obtained with MCP-7 and MTS-7 were in mutual agreement within their 3σ intervals. Together with the fact that both materials are of LiF type, MCP-7 being ca. 30 times more sensitive to photons than MTS-7 it confirms the assumption of possibility to neglect the neutron contribution to the total TL response. Although MCNP cannot generate delayed gamma rays from fission, the relative distribution calculated using MCNP5 differs from measured one by less than 15%. The measured values of time behaviour of gamma source well correspond with the fact that the relative importance of delayed gamma source to the total gamma one decreases with the distance from the core.

Both TLD types proved its suitability to measure integral gamma fields parameters in the mixed neutron-gamma fields of zero power reactors. At VR-1 reactor the MTS-7 detectors safely enable gamma field parameters determination at higher powers up to nominal one (1 kW), whereas very sensitive MCP-7 TLDs are more suitable for lower power levels or for measurement in regions remote from the core.

References

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