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Graphite reflecting characteristics and shielding factors for Miniature Neutron Source Reactors

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ABSTRACT

The usability of graphite as a reflector for MNSRs is investigated in this paper. Its use is optimized and shielding factors are calculated. Graphite seems to be compatible with liquid water. As a reflector, graphite proves to be usable as well, but it decreases the fuel cycle lifetime by about 7%.

To optimize its use the average worth reactivity of the unit volume was assessed for the different modes of filling the shim tray of the reactor with graphite which were: RIOS, RIOC, ROIS, and ROIC modes for the radial direction, and ASM, and ACM modes for the axial one. This quantity was found to be maximum for the ROIC mode reaching more than 0.01 mk/cm^3. The shielding factors for the radial and axial filling modes were found to be 0.7101 and 0.6266, respectively.

1. Introduction

Graphite is one of the most important materials for nuclear industry. It has been used extensively as moderator in power reactors and is still being used for the vigorously advancing High Temperature Gas Reactors (HTGR) (Rahn et al., 1984). Reflectors require the same characteristics that moderators have: a small atomic weight, a high scattering cross section, a high slowing-down power, and a low absorption cross section. Table 1 shows some reflectors with their moderating characteristics.

Graphite of high purity has good reflecting characteristics, and can be obtained at reasonable cost, but reactor-grade graphite is made artificially by graphitization of petroleum coke since the naturally occurring graphite is not sufficiently pure to be used directly in the reactor.

Miniature Neutron Source Reactors (MNSRs) are small research reactors of the Tank-in-pool type which use beryllium as reflector. One central control rod (CR) controls the reactor. The reactor is cooled and moderated by light water. A typical MNSR is depicted schematically in Fig. 1, and a summary description is given in Table 2 (Guo et al., 1993). The Tank which appears in Fig. 1 (30 cm internal radius) is in turn immersed in a large pool, 127.0 cm internal radius and more than 560 cm height. The height of the Tank is about the same height of the pool.

MNSRs have an initial excess reactivity (IER) of about 4.0 mk (Guo et al., 1993).These reactors use the addition of the top reflector (TR) in the shim tray (ST) after 1–2 years from their 1st start-up to keep the IER nearly constant through the fuel lifetime. The IER decreases with time for both fuel consumption and poisoning effects of xenon and samarium. The TR is expected to help the reactor run up to the design life of the fuel of 10 years, after which the fuel is expected to be changed as one batch.

Three beryllium blocks appear in Fig. 1;

1. The lower block: it is a circular plate with 14.5 cm external radius, 0.925 cm internal radius, and 5 cm thickness.
2. The side annular block: it is a cylindrical sector having 11.55 cm internal radius, 21.75 cm external radius, and 23.85 cm height.
3. The upper block: it is not really a block. It is a place where a number of semicircular pieces of metallic beryllium (or whatever reflector material) can be added in the ST as long as the reactivity of the reactor decreases for fuel consumption and other xenon and samarium poisoning as aforementioned.

Shielding (or self-shielding) factor is intended here as the ratio between the shielded worth of the TR piece (or sector) and the unshielded value. The piece or sector is considered as "unshielded" when it is added in the ST alone (singularly), while it is considered as "shielded" when it is added to the ST with the presence of other adjacent reflector pieces. This definition is made to show how the

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Table 1
Characteristics of selected reflectors (Rahn et al., 1984).

	H_2O	D_2O	Be	Graphite
Atomic weight	18.0	20.0	9.0	12.0
Density (g/cm^3)	1.0	1.10	1.84	1.57
Macroscopic scattering cross section (epithermal) (cm^{-1})	1.64	0.35	0.74	0.39
Macroscopic absorption cross section (thermal) (cm^{-1})	22E−3	85E−6	1.1E−3	0.37E−3
Average number of collision to thermalize, slowing-down power (cm^{-1})	19.6	35.7	88.4	115
Moderation ratio	70	12,000	150	170

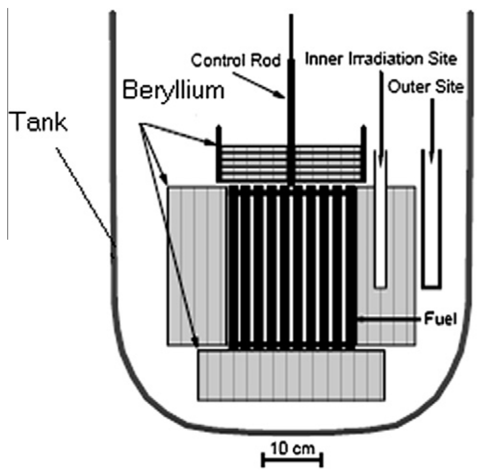

Fig. 1. A schematic longitudinal cross section of a typical MNSR.

Table 2
Characteristics of a typical MNSR.

Parameter	Description
Reactor type	Tank-in-pool
Rated thermal power	~30 kW
Fuel	UAl_4 dispersed in Al matrix
Fuel pin inner radius without cladding (mm)	4.3
Fuel pin outer radius with cladding (mm)	5.5
Fuel pin length (mm)	230
Cladding composition	Al
U-235 percentage in the fuel pin	24.83
U-235 enrichment	~90%
Fuel density (g/cm^3)	3.456
Core shape	Cylinder
Core diameter	23 cm
Core height	23 cm
Fuel elements number in the core	347
Control rod length (mm)	260
Control rod outer radius (mm)	2.45
Absorber of the control rod	Cd
Absorber internal radius (mm)	1.95
Total number of irradiation sites	10
Number of Internal Irradiation Sites (IIS)	5
Number of External Irradiation Sites (EIS)	5
Thermal neutron flux in IIS	1×10^{12} n/cm^2. *s*-at rated power
Thermal neutron flux in EIS	5×10^{11} n/cm^2. *s*-at rated power
Radial reflector thickness	10 cm

reflecting characteristics of a piece of reflector varies when other pieces of the same reflecting material are present, in analogy with the self-shielding concept defined for the nuclear fuel which makes the superficial layers of the fuel absorb more neutrons than (shield) the interior layers.

Since beryllium is a costly material compared to graphite it is worthy to study the usability of graphite as a TR in MNSRs. Graphite is compared with only beryllium since the latter is absolutely the best reflector for MNSRs (Albarhoum, 2007). The other reflecting materials are studied separately in other works.

This paper fixes three objectives to be hopefully accomplished:

1. To demonstrate the usability of graphite in MNSRs as TR.
2. To optimize the use of the TR obtaining its maximum reactivity/unit volume.
3. To calculate the so called self-shielding (or shielding) factors for the optimized configurations.

Although a completely filled ST with graphite has the same reactivity worth (or worth of the unit volume of reflector) whatever the filling mode be, the partial fill of the ST with reflector which means the way, the position, and the volume of the piece of reflector may change a lot the worth of the unit volume of reflector. This is the second objective of this paper as just mentioned and will be seen in the following sections.

2. Usability of graphite in MNSRs as reflector

To demonstrate the usability of graphite in MNSRs two features of graphite should be studied: the compatibility with light water as a coolant, and the Wigner effect.

2.1. Compatibility of graphite with water

Graphite reacts with water vapor (Glasstone and Sesonske, 1980) only. Graphite does not react with liquid water at the low temperatures MNSRs work at (~40 °C). Even in the case of the Design Basis Accident (DBA), in which the whole reactivity of the core is promptly released, the coolant temperature in the core will stay around 60 °C (Guo et al., 1993) which is far from vapor temperature. Graphite therefore does not have any problems regarding the compatibility with water.

2.2. Wigner effect in MNSRs

Although accumulation of energy may occur at temperatures below 100 °C its release (Wigner effect) is not expected to occur at temperatures less than 100 °C (Glasstone and Sesonske, 1980). it is obvious that these temperatures are far from the working temperatures of MNSRs (which are about 40 °C). Even in the accidental conditions (DBA), as mentioned earlier, the working temperature is about 60 °C only. Graphite can therefore be used in MNSRs as reflector.

3. Methodology for group constant and reactivity calculation

Group constants (GC) are intended here as a set of macroscopic cross sections and constants such as: the macroscopic diffusion coefficient, the macroscopic absorption cross section, the macroscopic scattering cross section, and the macroscopic fission cross section which the calculation of the reactivity is based on.

These cross sections and constants are calculated by the BMAC system (Albarhoum, 2008) which uses the WIMSD-4 code (Askew et al., 1966) for calculating the unit cell constants and the reactor core calculation code CITATION (Fowler et al., 1971) for reactivity calculation using the criticality option and diffusion theory. The unit cell GC and other parameters are so calculated by WIMSD-4 and the reactivity is calculated by CITATION utilizing these