Gamma heat analysis in various power levels of RSG G.A.
Siwabessy silicide core

A Rohanda¹,², A Waris¹, R Kurniadi¹, Kiswanta² and I Husnayani²

¹ Department of Physics, Institut Teknologi Bandung Jl. Ganeca, Lb. Siliwangi, Coblong, Bandung 40312
² Center for Nuclear Reactor Technology and Safety (PTKR), National Nuclear Energy Agency of Indonesia (BATAN) PUSPIPTEK Area Bldg No. 80 Serpong, Tangerang Selatan 15310
awaris@fi.itb.ac.id

Abstract. Reaktor Serba Guna G.A. Siwabessy (RSG-GAS, previous name MPR-30) is the largest research reactor in Southeast Asia that acts as a national facility to irradiate material. Gamma heat is a very important factor for the safety analysis in every material irradiation activity at the irradiation facility. Gamma heat is the main research topic of several forms of safety investigations at world research reactors. Gamma heat information is useful to predict the temperature of the material to be irradiated and negligence in predicting gamma heat can cause overheating. Gamma heat values are very dependent on the characteristics of the reactor core. Changes in reactor power can affect the core characteristics. RSG-GAS is designed to have a 30 MWth of nominal power but it is currently operated at 15 MWth power level. In this study observed changes in gamma heat as a function of reactor power and material target on the Central Irradiation Position (CIP) silicide core of RSG-GAS by using a modified GAMSET program. Modifications are made by adjusting the material and power configuration in the core. The results of the analysis show that gamma heat will be increase in accordance with the increase in power level in various material targets such as graphite (C), aluminium (Al), iron (Fe) and zirconium (Zr). Gamma heat also tends to increase according to the increase of atomic number target. Verification has been carried out with the results of calculations in the 35 MWth CEA Grenoble reactor with the smallest yield difference of 1.23% in the graphite target and 2.71% in the iron target.

Keywords: RSG-GAS, gamma heat, core power, GAMSET

1. Introduction
Reaktor Serba Guna G.A. Siwabessy (RSG-GAS, previous name MPR-30) is one of the nuclear reactors operated by The National Nuclear Energy Agency of Indonesia (BATAN) located in the Serpong Science and Technology Research Center (Puspiptek). As a research reactor, RSG-GAS serves as a place to irradiate material so that the gamma intensity value must be considered carefully, especially the impact of gamma heating that occurs in irradiated material. Gamma heating profile are useful for estimating the temperature of the heat that occurs in the core and for determining the cooling system capacity. Failure in predict gamma heating values can result in over heating of the material (Lemaire et al, 2013). Gamma heat is the main research topic of several forms of safety investigations in world research reactors, as has been done by Lee et al (2001), Guardini (1972), Reilly and Peters (1970), and Varvayanni et al (2008). Determination of gamma heating can be performed by measurement and calculation. Gamma heating measurement is carried out using a gamma calorimeter. Revitalization of the calorimeter is the main obstacle considering that the calorimeter is expensive,
often damaged and difficult to repair due to the use and exposure of high radiation fields. Experimental activities can also disrupt material irradiation service schedules. Therefore the determination of gamma heating by calculation simulation is preferred. Calculation of gamma heating in the core of a research reactor in Indonesia was pioneered by Setiyanto et al (1992) with the GAMSET code applied to RSG-GAS. The code compiled in the Fortran language originally made specifically for gamma heating calculations in the 35 MWth CEA Grenoble reactor (France) which has similar geometry (Setiyanto, 1991).

Gamma heating value that occurs is very depend on the type of material (target) and the whole characteristics of the reactor core. Changes in reactor power level can affect core characteristics. Hence, it is necessary to predict the gamma heat absorbed by the material to be inserted into the core at various reactor operating power levels. RSG-GAS is designed to have 30 MWth nominal power but it is currently operated at a 15 MWth power level. In this study, observation of gamma heat as a function of power level and target material in Central Irradiation Position (CIP) of RSG-GAS silicide core was conducted by using the modified GAMSET program. Variations in operating power levels ranging from 5 MWth, 10 MWth to 30 MWth with target materials in the form of Carbon, Aluminum, Iron and Zirconium.

2. Theory

The source of gamma radiation when the reactor operates is produced from three processes, namely neutron capture, fission and decay (Martin and Harbison, 2006). The resulting gamma radiation will interact with the material in the reactor core through the photoelectric effect mechanism, compton scattering and pair production so that it will cause heat in the material exposed to high intensity gamma radiation. The heat is commonly referred to as gamma heating. However, in the state of the reactor operating at a fixed power, the gamma intensity will be constant and directly proportional to the reactor's power, but it still varies as a function of the position in the core. Gamma interaction with the material will reduce the intensity of the gamma and also cause heating in the material due to the gamma energy absorbed by the material. The greater the effect of attenuation, means the greater the heating that occurs in the material. Gamma heat generation at any point on the reactor core can be expressed in the form of general equations as follows (Jaeger et al., 1968):

$$P(r) = C \int_{E_{\text{min}}}^{E_{\text{max}}} E \frac{\mu(E,r)}{\rho} \phi(E,r) dE$$

with,

- $P (r)$ : gamma heat (W/g);
- $E$ : gamma energy (MeV);
- $\phi (E, r)$ : gamma flux as an energy function (E) and position (gamma/cm² • s MeV);
- $\mu_o$ : coefficient of macroscopic absorption (cm⁻¹);
- $\rho$ : mass density of absorbent material (g/cm³);
- $C$ : $1.6 \times 10^{-23}$ (W • s / MeV).

The above equation shows that gamma heat generation in a material will be depend on the type of material and its energy spectrum.

3. Methodology

This research was conducted with several main stages, including the preparation of gamma sources, preparation of RSG-GAS silicide core data, power peaking factors at various power levels, target material data and gamma heat calculation simulations with modified GAMSET.
3.1. Determination of RSG-GAS gamma sources

Gamma source of RSG-GAS siliside core at various power levels was prepared by using ORIGEN2 code. Calculated gamma source data is shown in Table 1.

Table 1. Gamma source of RSG-GAS siliside core at various power level by ORIGEN2

| No. | Mean E\(\gamma\) (MeV) | 5 MWth | 10 MWth | 15 MWth | 20 MWth | 25 MWth | 30 MWth |
|-----|------------------------|--------|---------|---------|---------|---------|---------|
| 1   | 0.1                    | 3.65E+16| 7.28E+16| 1.09E+17| 1.45E+17| 1.82E+17| 2.18E+17|
| 2   | 0.5                    | 1.94E+16| 3.88E+16| 5.81E+16| 7.75E+16| 9.68E+16| 1.16E+17|
| 3   | 1.5                    | 2.90E+15| 5.81E+15| 8.71E+15| 1.16E+16| 1.45E+16| 1.74E+16|

3.2. Preparation of the characteristics of the RSG-GAS silicide core data

The core characteristic data has been prepared in material configuration form (shown in Figure 1) and power peaking factors (ppf) configuration at various power levels 5 - 30 MWth (shown in Figure 2). These data are used as core data input on GAMSET.

Figure 1. Configuration of RSG-GAS silicide core
3.3. Preparation of material target characteristics data

Material target data in the form of elements of Carbon (C), Aluminum (Al), Iron (Fe) and Zirconium (Zr) with 5 days irradiation time (based on operating cycle of RSG-GAS).

3.4. Gamma heating analysis using modification GAMSET

Analysis of gamma heating was conducted using GAMSET with several modification parameters adjusting into RSG-GAS silicide core. Analysis was carried out at various power levels (5, 10, 15, 20, 25 and 30 MWth) at position E7 in CIP on various target materials such as C, Al, Fe and Zr.
4. Results and Discussion

The calculated gamma heating on various target materials at E7 position in the Central Irradiation Position (CIP) of the RSG-GAS silicides are shown in Table 2.

Table 2. Results of calculated gamma heating at [E,7] position in CIP

| No. | Material target | Z | Gamma heating (W/g) |
|-----|-----------------|---|---------------------|
|     |                 |   | Power level         |
|     |                 |   | 5 MWth   | 10 MWth | 15 MWth | 20 MWth | 25 MWth | 30 MWth |
|-----|-----------------|---|---------------------|
| 1   | Carbon          | 6 | 0,95 (16,67%)       | 1,88    | 2,84    | 3,75    | 4,71    | 5,64    |
| 2   | Aluminium       | 13| 0,93 (33,33%)       | 1,86    | 2,80    | 3,70    | 4,64    | 5,56    |
| 3   | Besi            | 26| 1,15 (50,00%)       | 2,28    | 3,45    | 4,55    | 5,71    | 6,83    |
| 4   | Zirconium       | 40| 1,57 (66,67%)       | 3,13    | 4,72    | 6,23    | 7,81    | 9,35    |

Table 2 shows that the increase in power level causes an increase in gamma heating in various target materials. This is in accordance with equation 1 which states that the gamma heating is proportional to the flux or thermal power.

The calculated results as a function of core power level and material targets are shown in Fig 3.

Figure 3. Gamma heating of RSG-GAS silicide core at position [E-7] in CIP

Fig 3 illustrates the increase in gamma heating occurring linearly in various target materials (C, Al, Fe and Zr) which are irradiated in the core. Significant increase in gamma heating mainly occurs in elements with Z > 13. Gamma heating in Fe and Zr increases significantly as a power function. This is due to the coefficient of mass attenuation and density of each target material as an important factor in determining gamma heating. Coefficient of mass attenuation and density of each target material shows the quality of energy absorbed (deposited) in the material. The combination of these two factors is known as the mass energy-absorption coefficient ($\mu_a/\rho$) as an energy function. The coefficient values for various materials will increase significantly, especially at low energy ($E_\gamma = 0 - 0.25$ MeV or $\bar{E}_\gamma =$...
0.1 MeV) as shown in Fig 4. In the GAMSET calculation, the gamma energy spectrum is divided into 3 groups: low energy groups (0 - 0.25 MeV), medium (0.25 - 0.9 MeV) and high (> 0.9 MeV).

![Gamma Heating vs. Mass Absorption](image)

**Figure 4.** Correlation of mass energy-absorption coefficient and gamma heating as a function of the material target at position [E-7] in CIP RSG-GAS

Increase the mass energy-absorption coef. value (secondary axis) proportional to the increase in gamma heating. Coefficient value in the light elements (Z <13) are relatively fixed therefore the gamma heat between Carbon elements (Z = 6) and Aluminum (Z = 13) is almost similar in value, ranging from 5.6 - 5.7 W/g.

Fig 4 also shows comparison calculated gamma heat with experimental results on CIP positions at a power level of 30 MWth. It was confirmed that the calculated gamma results agreed with the measurements with smallest deviation 1.94% (Fe target). Modifications applied to GAMSET are power configuration changes and mass configuration of core, from uranium oxide (U₃O₈-Al) to uranium silicide (U₃Si₂-Al). In general, gamma heating of the silicide core is lower than the oxide terrace, with yield deviations of 1.23% (C target), 3.64% (Al target), 2.71% (Fe target) and 9.23% (Zr target). According to Setiyanto et al (2001), replacing fuel elements from oxides to silicides can reduce gamma heating evenly by about 1%. Lower gamma heating can be reached by increasing the density of the uranium fuel element. RSG-GAS currently uses 2.99 g/cc of fuel element density. Variations in density changes can be made up to 3.55 g/cc by considering manufacture aspects. Higher fuel density is more beneficial because it can extend the operating cycle and be safer because the resulting gamma heat is lower.

### 5. Conclusion

From the results and discussion it was concluded that an increase in the reactor power level causes a linear increase in gamma heating. The gamma heating increase occurs linearly according to the increase in the target atomic number with a significant increase occurs in the intermediate and heavy category targets (Z> 13): Fe and Zr. The mass energy-absorption of low gamma energy \(E_\gamma = (0 - 0.25\) MeV) has a significant role in changing the gamma heat value compared to other energy spectrum ranges.
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