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Safety analysis of the irradiation of Tellurium (Te) target in G.A. Siwabessy Reactor

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Abstract. Safety Analysis of the Irradiation of Tellurium (Te) Target in G.A. Siwabessy Reactor. Providing public service becomes one of the priority programs made by the Head of BATAN, such a program is the radioisotope production of Iodine 131 (I-131), which emits gamma and beta that are utilized for medical purpose. The radioisotope can be produced by irradiating the target of Tellurium dioxide (TeO_2) on the G.A. Siwabessy Reactor core. Tellurium dioxide (TeO_2) is irradiated on the position of Central Irradiation Position (CIP) D-6 and E-7 because the Irradiation Position (IP) is used for Topaz irradiation and CIP (D-6, E-7) is used for the irradiation of Low Enriched Uranium (LEU). Based on the several safety requirements such as analyze the optimum amount of the Tellurium target on CIP (D-6, E-7) with Topaz and LEU. The scope of the research includes the reactivity disturbance, radial power peaking factor and thermohydraulic disturbance. The diffusion group constant of the model uses the program of WIMSD-5B and the result is used for calculating reactivity disturbance and radial power peaking factor with the program package of BATAN-2DIFF. The thermohydraulic disturbance is calculated with using the Generalized Gap Temperature Calculation (GENGTC) program. The calculation of the reactivity of 750 gram (6x125 gram) Tellurium is resulting the change of negative reactivity of -0.27% $\Delta k/k$ and the value of radial power peaking factor is 1.34 and the temperature at the center of TeO_2 target is 366.7^0C and outside the capsule (Aluminum) is 58.39^0C, if it is compared to the safety margin of $\pm$ 2% $\Delta k/k$, $PPF_{rad\ max}$=2.6, melting point of Al=660^0C, melting point of Te=449.5^0C, so all the parameters still meets the safety requirement.

1. Introduction

The development and utilization of radioisotopes and radiopharmaceuticals for the welfare of the societies are one of the missions of Head of National Nuclear Energy Agency (BATAN) as a national program. In supporting these activities, the Center of Multipurpose Reactor performs its function as a neutron provider which facilitates the users to irradiate targets.

In Indonesia, the availability of radioisotopes for medical purposes becomes a priority, one of which is Iodine-131 (I-131). I-131 is a gamma-transmitting radioisotope at a maximum energy of 610 keV with a half-life (T½) 8.02 days so that it can be used for diagnostic and therapeutic purposes in nuclear medicine [1-4]. The I-131 production process was obtained from the induced neutron reaction to the tellurium target (TeO_2) which was carried out in an irradiation facility on the G.A.Siwabessy Multipurpose Reactor (RSG-GAS) core. Targets that will be positioned in the irradiation facility can cause reactivity disturbance, both positive and negative reactivity.

Nowadays, domestic and international market demand for Iodine-131 continues to increase, by the fact, determining the capacity of irradiating TeO_2 together with optimum topaz and LEU needs to be done. Other studies of irradiation for single or mixed targets with other radioisotope targets such as LEU

[3], Gd_2O_3 (produce 161Tb) [4], MoO_3 [5], Sm_2O_3 have been conducted. The purpose of this study was to analyze the irradiation of TeO_2 targets with mass variations in the CIP position (D-7 and E-6) for thermohydraulic disruption, reactivity and the maximum radial power peaking factor ($PPF_{rad\ max}$).

This paper calculated cell for a stringer, TeO_2 targets with different mass various from 125 grams to 750 grams using the WIMSD-5B [6] program that has been validated to produce diffusion group constants. Core calculations are performed using the 2-D Dimension (2-D) BATAN-2DIFF neutron diffusion program package in the X-Y geometry model to calculate reactivity changes, $PPF_{rad\ max}$. Thermohydraulic (heat transfer) calculations were performed the Generalized Gap Temperature Calculation (GENGTC) program package [8].

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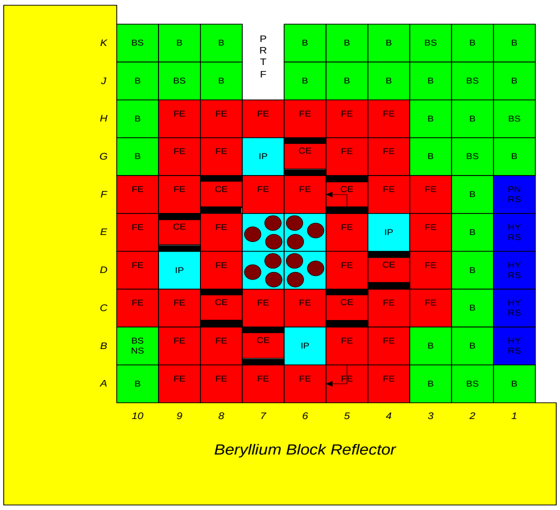
2. Description of RSG-GAS Core and TeO_2 Target

The RSG-GAS is an MTR (Material Testing Reactor) research reactor with a nominal power of 30 MW (thermal). The RSG-GAS core is composed of 40 standard fuel elements (FE) and 8 control fuel elements (CE) and several beryllium refractor elements (Be) in 10 × 10 core grid positions as shown in Figure 1. The core provides several positions for target irradiation namely CIP (central irradiation position), IP (irradiation position), PNRS (pneumatic rabbit system) and HYRA (hydraulic rabbit system), each consisting of 4, 4, 1 and 3 core grid positions. Targets that require a long period of irradiation use CIP or IP positions. The "L" shaped beryllium reflector block is placed on two sides of the porch to increase the neutron flux that will be used in the neutron beam tube placed in the reflector block. The fuel of the reactor is uranium silicide (U_3Si_2-Al) low enrichment (≤19.75%) with an active core height of 60 cm [9].



Notes : FE = Standard Fuel Element, CE = Control Fuel Element, BE = Be Reflector Element, BS = Be Reflector Element with *plug*, IP = Irradiation Position, CIP = Central Irradiation Position, PNRS = *Pneumatic Rabbit System*, HYRS = *Hydraulic Rabbit System* (burn-up classes are in the second raw)

Irradiation Facilities:
CIP D-6 and E-7 for the LEU irradiation
IP B-6, D8, E-4 and G-7 for topaz irradiation
CIP D-7 and E-6 for TeO_2 irradiation

Figure 1. Configuration of RSG-GAS Core with Target.

CIP and IP positions are used for irradiating targets that require high average thermal neutron flux, such as targets for isotope production. On a nominal power, the average thermal neutron flux in CIP and IP is 2×10^{14} neutrons $cm^{-2}s^{-1}$. Therefore CIP and IP are suitable for topaz and LEU irradiation in the production of 99Mo radioisotopes. Nowadays, the CIP which used for LEU irradiation are D-6 and E-7

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and topaz irradiation is positioned on all IP positions (B-6, D-9, E-4 and G-7). TeO_2 is irradiated at the CIP position (D-7 and E-6). Irradiation of TeO_2 targets in capsules requires stringer which used for guidance so that the target is placed in the specified position. The stringers used in the RSG-GAS are presented in Figure 2, which are placed in a core grid position, so that a CIP grid position can irradiate 3 capsules. All targets in the capsule irradiated in the core of the RSG-GAS are placed on the stringers. The determination of stringer in CIP with the TeO_2 targets positioned at D-7 and E-6 is shown in Figure 1.

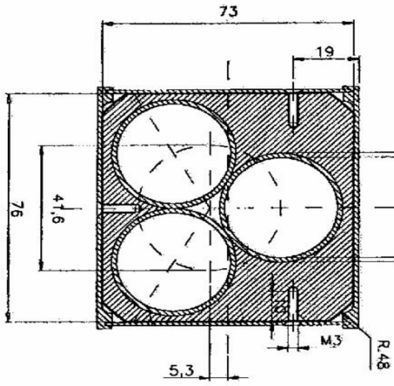

Figure 2. Stringer of TeO_2 Target Capsule.

3. Methodology

3.1 Calculation of Heat Transfer

The gamma heating generated at the target and capsule needs to be discharged into the reactor cooling system, so as not to jeopardize the integrity of the target. In preventing a high increase in target temperature, the target is positioned into a layered capsule with the deepest arrangement containing the target which is positioned into the Quartz capsule with an inner diameter of 13 mm, the outer diameter of 15 mm and height of 50 mm. Other capsule layer of aluminum with the inner diameter of 21.4 mm, outer diameter of 24.4 mm and height of 200 mm where between the quartz capsule and Aluminum capsules are filled with He gas, then the outer layer is an Aluminum tube with an inner diameter of 25.4 mm, outer diameter of 30.4 mm and height of 500 mm axially as shown in Figure 3.

Temperature profiles from the target center to the outer wall of the capsule during irradiation can be calculated using the GENGTC (Generalized Gap Temperature Calculation) program package. The GENGTC program calculates heat transfer by conduction and radiation in a radial direction or one dimension. Inputs from the GENGTC program are material type, emissivity, density, conductivity, gamma heating and fission heat of the material, capsule dimensions, coolant temperature and cooling convection coefficient.

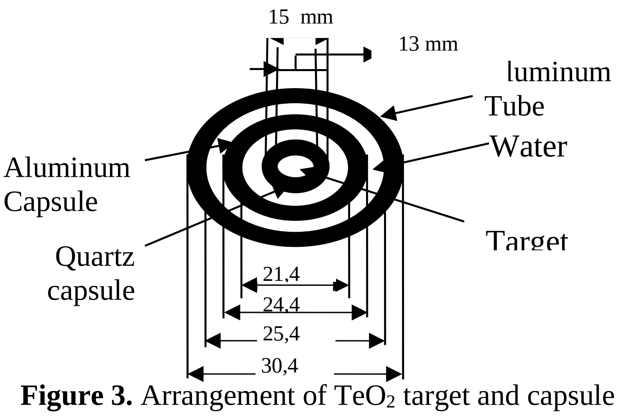

Figure 3. Arrangement of TeO_2 target and capsule.

3.2 Neutronic Calculation

The calculation of stringer cells and the TeO_2 target is carried out using the WIMSD5B program package to generate group constants in 4 neutron power groups with nuclear data of ENDF / B-VII.1. The upper boundary of the neutron power group is 10 MeV, 0.821 MeV, 5.530 keV and 0.625 eV. TeO_2 target cells can be modeled in 2 parts of ½ lattice and ¼ lattice for each position in CIP (D-7 and E-6) according to the stringers configuration used. This cell model as shown in Figure 4, has been used in previous researches using the same stringers. Because the core calculation is done for 2-dimensions (2-D), all target parts are homogenized in 1 cell according to the volume fraction of each cell's material. Cell calculations are performed for:

1. Generation of diffusion group constants for stringer targets using ¼ lattice model and ½ lattice CIP position.
2. Generation of diffusion group constants for TeO_2 targets with ¼ lattice models and ½ lattice of CIP positions of 125 grams each.

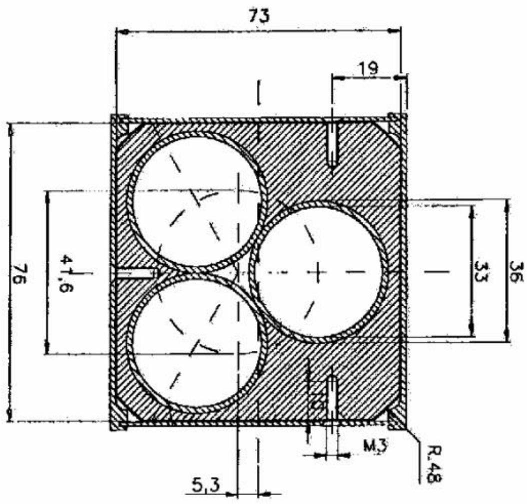

Figure 4. ½ and ¼ lattice model of CIP position for LEU target.

The core calculation uses the BATAN-2DIFF program package, so that the full core of the RSG-GAS, including the target, is modeled in the X-Y (2-D) geometry model with the condition of the vacuum limit on each side of the core. The core parameters that are calculated are the change in core reactivity (Δk / k), and the change in the maximum radial power peaking factor ($PPF_{rad\ max}$).

The limit used in the irradiation of the TeO_2 target, topaz with U-235 changes in maximum target reactivity is 2% Δk / k and the change in the maximum radial power peaking factor ($PPF_{rad\ max}$) does not exceed 2.6. These limits are chosen to guarantee the reactor is in a safe condition in accordance with Safety Analysis Report limitations of RSG-GAS [9-11].

4. Results and Discussion

4.1 Calculation of Heat Transfer in Capsules

The temperature calculation for each irradiated target is carried out using the GENGTC program. Important parameters that become the input in this calculation are:

- The coolant flow rate which passes the target inside the stringers
- Coolant convection coefficient
- Gamma heating on target, Al material, quartz
- Density and coefficient of heat conduction

For the cooling fluid velocity of 3.1 m/s with the cooling fluid (water) at 49°C, with the input data above, therefore the following results are obtained.

Table 1. Distribution of Capsule and TeO_2 target.

No	Position of target arrangement	Temperature (°C)
1	Target Center	366,6968
2	Quartz (*Inner Capsule*)	334,6781
3	Quartz (*Outer capsule*)	334,2753
4	Al Capsule (*Inner Capsule*)	58,9591
5	Al Capsule (*Outer Capsule)*	58,3936

From the results of the temperature calculation, it shows that the integrity of the quartz tube and Al tube is still maintained at that temperature, because quartz has a melting point of 1425°C and a melting point of Al ≈ 660°C. Whereas the TeO_2 metal powder target has not yet melted (Te metal melting point ≈ 449.5°C). From GENGTC calculations all materials still meet the operational safety limits

4.2 Neutronic calculation
The results of neutronic calculations are shown in Table 2 by counting each entry of a 45 cm high topaz target in 4 IPs and 3 grams weight LEU in CIP (D-6 and E-7) in each stringer hole. This calculation has been done in previous studies [12]. This results in the initial value of reactivity to calculate changes in reactivity and the maximum radial PPF when the TeO_2 target positioned into the CIP position (D-7 and E-6).

Table 2. Value of PPF and reactivity of 45 cm high topaz and 3 gram LEU U-235.

	Mass (gram)	Reactivity ($\Delta k/k$)	Reactivity change	$PPF_{rad\ max}$	Position
Stringer	0	8.70E-02	0.00E+00	1.31	F-8
Topaz and QtE73g	3	8.82E-02	1.22E-03	1.32	F-8
Topaz and QtQbE73g	6	8.92E-02	2.15E-03	1.33	F-8
Topaz and AllE73g	9	9.15E-02	4.54E-03	1.34	F-8
Topaz and AllE7d6qt3g	12	9.44E-02	7.42E-03	1.34	F-8
Topaz and AllE7d6qtqb3g	15	9.50E-02	8.04E-03	1.34	F-8
Topaz and Alle7d63g	18	9.68E-02	9.74E-03	1.34	F-8

Calculation of reactivity of a TeO_2 target in the CIP position (D-7 and E-6), previously required to calculate the reactivity and peak power factor (PPF) arising from the inclusion of the target stringer as a place of irradiation modeled and the topaz target in the IP position and LEU target in CIP (D-6 and E-7). Each stringer has 3 irradiation holes. Each CIP stringer (D-6 and E-7) is filled with LEU @ 3gram and 4 IPs filled with 45 cm high topaz. The results of these calculations are to calculate the change in reactivity from the value difference caused by the entry of TeO_2 in the CIP stringer (D-7 and E-6).

The target calculation is done with several combinations of irradiation positions, namely QtE6125g (quarter top at E-6 position filled with 125 g) means that E-6 irradiation position on 2 of ¼ lattice is filled with 125 g, Then the AllE6D7qt125g is the E-6 irradiation position all holes are filled @ 125 grams and the ¼ lattice of the top of the D-7 lattice is filled with 125 g, AllE6D7qtqb125g means the E-6 irradiation position is all filled with 125 g and 2 of ¼ lattice are filled with 125 g. And AllE7D61g means that all irradiation positions D-7 and E-6 are filled with 125 g or all irradiation positions of CIP D-7 and E-6 are filled with @ 125 g TeO_2. The results of these calculations are shown in Table 3 below:

Table 3. The reactivity change of TeO_2 target mass with 45 cm high topaz and 18 grams LEU.

	Mass of TeO_2 (gram)	Reactivity *(Δk/k)*	Reactivity change	$PPF_{rad\ max}$	Position
Topaz and Alle7d63g (T+LEU)	0	9.68E-02	0	1.34	F-8
(T+LEU) and QtE6125g	125	9.42E-02	-0.24	1.32	F-8
(T+LEU) and QtQbE6125g	250	9.33E-02	-0.19	1.32	F-8
(T+LEU) and ALLE6125g	375	9.24E-02	-0.18	1.33	F-8
(T+LEU) and ALLE6 QtD7125g	500	9.20E-02	-0.20	1.34	F-8
(T+LEU) and ALLE6 QtQbD7125g	625	9.15E-02	-0.25	1.34	F-8
(T+LEU) and ALLE6D7125g	750	9.09E-02	-0.27	1.34	F-8

Table 3 shows the reactivity change *Δk/k* for each addition of TeO_2 target that has a different trend when it added 125 grams on the position of ¼ top lattice with the value of 0.24%, whereas the addition of 125 grams to another 2 lattices made a decrease on the reactivity to -0.18%. After the addition of the next 125 grams target at position D-7 in the upper lattice position, the reactivity will rise after the next target is added until the CIP position (D-7 and E-6) is fully filled with a target of 750 grams (6x125 grams) and the reactivity becomes -0.27% which is the highest value. The minimum shutdown margin reactivity (ρ_{OSR}) is -0.5% Δk/k [11].

For $PPF_{rad\ max}$ value, each addition of the TeO2 target has an upward trend after adding targets in the CIP E-6 position, all grids are 125 grams filled, but the increase is not significant, and all with $PPF_{rad\ max}$ values at F-8 positions. From the calculation, it shows that for topaz irradiation (height 45 cm), the mass of 18 grams LEU (6x3 grams) and TeO_2 loaded in 6 lattices (D-7 and E-6) or equal to 750 grams has a reactivity value Δk/k of -0.27% and $PPF_{rad.max}$ = 1.34, this value is still below the permitted limitations in the Safety Analysis Report [9].

Conclusion

From the results of calculations with GENGTC for heat transfer, the temperature at the center of the target and the temperature in the capsule is smaller than the melting point, so that the integrity of the target and the capsule is still maintained, while the neutronic calculation with BATAN-2DIFF shows that if the IP position is filled with topaz with a height of 45 cm, CIP (D-6 and E-7) filled with 18 gram LEU and CIP (D-7 and E-6) filled with TeO_2 target reactivity change Δk/k maximum of -0.27%, $PPF_{rad.max}$ = 1.34 this value does not exceed the safety limitations where the largest value of Δk/k is ±2% and $PPF_{rad.max}$ 2.6.

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