Safety Study of topaz irradiation management at the in core RSG-GAS Position

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Abstract. Safety study of topaz irradiation management at the core rsg-gas position. A study of the management of Topaz stones in the irradiation process in the core position of the Multipurpose reactor G.A Siwabessy in the Batan Serpong (PRSG) has been carried out. A complex process of management because it must meet the technical and administrative requirements of the nuclear power supervisory body (BAPETEN), national and international transportation, and its safety management aspects. From the results of a study of hazard control and risk assessment (HIRADC) a risk rating with rating B is obtained, fulfilling the exposure aspect of container surface according to international transportation requirements (IATA) of <0.4 micro Sv/hour, production requirements as well as fulfilling transportation permits. In a predictable safety aspect, a management strategy has been made so that the potential hazards can be overcome, because the results of this study show that Topaz management in in-Core positions with acceptable risk and supervision is required. fulfill administrative requirements, permit the production and be safe for the executor, transportation and environment and fulfill the requirements for re-export.

1. Introduction
RSG - GAS reactor The BATAN Multipurpose Reactor Center (PRSG) in Serpong is a facility providing neutron sources with a mean neutron flux of $2 \times 10^{14}$ n / cm$^2$.s. As a neutron source provider facility, the operation of the reactor can be utilized by the user for utilization activities with the aim of research, radioisotope production, and topaz stone irradiation. Topaz stones are among the top stones that have a hardness value of 8 Mohs, below diamonds which have a hardness value of 10 Mohs. Topaz stones consist of clusters of silicon that contain a combination of aluminum together with fluorine and hydroxyl. It is called Topaz because it originates from the Topazos archipelago located in the Red Sea [1]. Topaz has been known since ancient Egypt. The Greeks believed topaz to provide power in terms of sight, both inner and physical sight of the beauty of topaz stone usually found in the form of crystals that have a prismatic sparkle and reflect the breakdown of light. Topaz breeding with neutron irradiation techniques can change the color of topaz from white to a certain color depending on the size of the neutron flux, the length of irradiation and the geometry of the base material. Topaz has the chemical formula AL2SiO4 (OH4F) 2 which, when reacting with neutrons, a nuclear reaction will occur which can cause reactivity
of 0.0741%. The core reaction products include P31, which is the result of Si31 decay emitting $\gamma$ and $\beta$ with a time of 2.62 minutes. In the neutron reaction with topaz, it is also possible to have a safety reaction to impurity contained in topaz with the irradiation position of the Topaz stone shown in Figure 1. The effect of this irradiation will cause the Topaz stone to changes its nature to become radioactive and emit radiation. The size of the exposure due to irradiation depends on the type of impurity (impurity) that exists in the natural topaz stone, both those that have a short half-life (second-order) to long (year order) and the length of irradiation on the reactor core. Therefore always special treatment is needed for topaz after irradiation. To maintain the safety of officers and the work environment, these activities must be controlled by the level of risk received by workers.

![Beryllium Block Reflector](image.png)

**Figure 1.** Layout in-core Topaz stone position

Safety worker and environmental controls in this activity are carried out with due regard to clause 3.2.1 of SB 006 OHSAS 2008 concerning the identification of hazard identification and risk determinant control (HIRADC)[2]. This clause states that hazard identification, risk assessment and control of activities, products and services must be considered when formulating a plan to meet OHS policies. The preparation of this HIRADC must be carried out as an activity control and safety assessment for radiation workers at the PRSG. Considering the existence of several important things, namely: potential radiation hazards, production permit requirements, international flight requirements, transit airport requirements and recipients; the requirements of the recipient country's regulatory body, the irradiation process must be carried out with a study that is more concerned with the level of radiation exposure when it will be sent for re-export, officers, transportation safety. The irradiated Topaz will be re-exported, it will also discuss international flight requirements for Dangerous goods. This paper will discuss the control of the calculation of the safety profile, control of engineering safety risks, fulfillment of the Topaz production permit requirements from BAPETEN, the re-export requirements, the safety requirements of local and international transportation, and the engineering actions that must be taken in managing Topaz stones.

2. **Theory**

In determining and considering the risk assessment of an activity, it always starts by identifying potential hazards in the workplace, then ranking, assessing and controlling risks according to clauses 3.1 to 3.6 SB 006.1-0HSAS 18001: 2008 [3,4]. Hazard identification, assessment and risk control are also part of the risk management that must be carried out in the workplace in accordance with ISO 31000 [4], as well as the regulations of the Head of the Nuclear Energy Supervisory Agency Number 4 of 2010.
concerning Nuclear Power Utilization Facility Management and Activities Systems [5]. The making of this HIRADC is a major factor in the implementation of a safety management system, as shown in Figure 2.

![Flowchart of the relationship between HIRADC and the Organizational Safety Management system](image)

**Figure 2.** Flowchart of the relationship between HIRADC and the Organizational Safety Management system

The existence of this HIRADC document is very useful when legal liability is needed in the event of an occupational accident, excessive exposure to workers, the fulfillment of transportation requirements and licensing requirements of the recipient country. To calculate the Risk (R) based on the contribution of the magnitude of the risk occurrence (P), you can use Table 1, while for the scale of the consequences (K) can be shown in Table 2. The combination of these three is very crucial in making the calculation of Risk (R).

\[
R = P \times (K_1 + K_2 + K_3 + K_4 + K_5) \quad \ldots \quad (1)
\]

with:
- \(R\) = Risk
- \(P\) = Opportunity
- \(K_1, K_2, K_3, K_4, K_5\) = Consequences

**Table 1. Risk scale (P)**

| Scale | Routine | Character |
|-------|---------|-----------|
| 1     |         | In theory it can happen, but has never experienced or heard of happening during the work |
| 2     |         | Has happened 1 (one) time at a time that is not known with certainty, over (one) time during the work |
| 3     |         | Ever happened within last 5 (five) Can occur at most 1 (one) time during work in progress |
| 4     |         | It happened in the last 3 (three) years It can happen 2 (two) to 3 (three) times this HIRADC during the work |
| 5     |         | Occurred in 1 (one) time Can occur more than 3 (three) times during work in progress |
### Table 2. Determining the consequence scale (K)

| Scale | Impact K3 (K1) | Radiation working area conditions (K2) | Individual doses acceptance (K3) | Living environment (K4) | Financial loss (K5) |
|-------|----------------|----------------------------------------|---------------------------------|-------------------------|---------------------|
| 1     | First aid in accidents | ≤ 5 mSv/year                            | ≤ 20 mSv/year                   | < BML (Environment quality standards) | X < 5%               |
| 2     | medical care         | 5 < dose ≤ 15 mSv/year                  | 20 < dose ≤ 200 mSv/year        | Recover by itself < 12 months | 5% ≤ X < 5%          |
| 3     | Permanent Disability 1-person | 15 < dose < 50 mSv/year | 200 < dose ≤ 500 mSv/year | Can be recovered by intervention in time < 12 month | 15% ≤ X < 30%         |
| 4     | Death of 1 person; Permanent disability > 1 person | ≥ 50 mSv/year | 500 < dose < 5000 mSv/year | Can be recovered right By intervention for a long time > 12 month | 30% ≤ X < 50%         |
| 5     | More than 1 person died | There is contamination ≥ 5000 mSv/year | Cannot be recovered in any way | X ≥ 50%                  |                     |

#### 3. Methods
The study in this paper is to analyze the risk profile (R) of safety based on document No.RSG.OR.08.03.41.10/00 regarding the identification of risk assessment and control in the process of topaz irradiation at the in-core position on the reactor core. The evaluation will evaluate the level of Gamma radiation exposure in the work area, personnel radiation exposure to hidden safety controls that may occur. In addition, it is also necessary to look at the records of accidents that have occurred, near-miss notes and input from relevant employees. In the second stage, after various hazards have been identified, a risk analysis of each hazard is carried out. The next stage for creating a safe and healthy workplace is to assess the likelihood that workers will come into contact with hazards or be exposed to the hazards and the severity of the consequences if they occur. The end result is the application of risk control to the safety profile obtained, as well as completing the required requirements, ranging from production permits, transportation requirements, production hazard control to engineering and the use of personal protective equipment (PPE). For data processing in this paper the RSG.OR.08.03.41.10/00 document on the risk assessment of Topaz stone management is in-core position [6,7].

#### 4. Results
In the discussion of this paper, it is grouped into 3 sections, namely effective control of the radiation safety risk profile, PPE usage, fulfillment of administrative aspects as BAPETEN permit requirements, re-export licensing, international transportation and engineering that must be carried out on the value of the safety profile. In Table 3 the safety profile is conveyed by displaying it at the process stage, while
the preparation and completion stages are not submitted because it has a minimum rating, namely "A". While the overall safety profile for Topaz stone management is "B" (the value is taken based on the highest risk).

Table 3. The safety profile of Topaz irradiation on the reactor core is in-core position.

| STAGE: Work implementation | 1 | 2 | 3 | 4 | Risk | 7 | 8 |
|----------------------------|---|---|---|---|------|---|---|
| Wash and weigh Topaz stones (before irradiation) | Wash and weigh Topaz stones (before irradiation) | Physical hazard (scratched) | Small wound | PPE, administrative procedure | 3 | 1+1+1+1 | A |
| Insert Topaz stones into capsules | Insert Topaz stones into capsules | Physical hazards (splashed into the reactor pond), physical hazards (tools falling) and radiation hazard | Contamination; broken tool; and stochastic effect | PPE, administrative procedure | 1 | 2+2+3+3+1 | A |
| Move in-core Topaz capsules to support | Move in-core Topaz capsules to support | Physical hazards (splashed into reactor ponds); physical hazards (tools falling) and radiation hazard | Contamination; broken tool; and stochastic effect | PPE, administrative procedure | 1 | 2+2+3+3+5 | A |
| Move Topaz capsules from support to the irradiated position (operator / supervisor) | Move Topaz capsules from support to the irradiated position (operator / supervisor) | Physical hazards (splashed into reactor ponds); physical hazards (tools falling) and radiation hazard | Contamination; broken tool; and stochastic effect | PPE, administrative procedure | 1 | 2+2+3+3+5 | A |
| Activity | Physical Hazards | Contamination | PPE, Administrative Procedure | Probability | Consequences | Rank |
|----------|------------------|---------------|-------------------------------|-------------|--------------|------|
| Lift and Move Topaz in-core capsules to the storage pool | Physical hazards (splashed into reactor ponds); physical hazards (tools falling) and radiation hazard. | Contamination; The reactor is Shutting down; stochastic effect | PPE, administrative procedure | 1 1+1+1+1+5 9 A | | |
| Pouring irradiated Topaz stones into the basket | Physical hazards (splashed into reactor ponds); physical hazards (tools falling) and physiological hazard | Contamination; Stochastic effect and fatigue muscles | PPE, administrative procedure | 1 2+2+3+3+1 11 A | | |
| Move irradiated Topaz stones to the storage warehouse | Physical danger (slip); physical hazard (radiation) physical hazard (Topaz falling) | Bruised, sprained | PPE, administrative procedure | 1 1+1+1+1+1 5 A | | |

Notes
1 = The main stages of activity
2 = Potential hazard
3 = As a result of an accident and / or PAK *)
4 = Control that has been done
5 = Opportunities (P)
6. Consequences (K)
7. Scale
8. Rank
*) occupational diseases

4.1. Safety risk control

The results of the HIRADC in this study are shown in Table 3, with the risk profile "B", ie risks not yet acceptable, additional control measures need to be taken. Additional controls must be made to ensure that risks are accepted, additional controls must be made based on the contribution of the dominant risk causes, namely exposure to radiation, use of PPE, ergonomic factors and fatigue.

Based on TLD measurements for 5 years for employees who manage Topaz, it is shown in Table 4.
Table 4. Data for the reception of external exposure of Topaz for 5 years (2013-2017)

| No. | Officer (name) | TLD measurement results, (calculated annually, mSv) |
|-----|----------------|-----------------------------------------------------|
|     |                | 2013  | 2014  | 2015  | 2016  | 2017  | ∑     |
| 1   | A              | 0.94  | 0.75  | 0.29  | 1.65  | 1.1   | 4.73  |
| 2   | B              | 0.07  | 0.06  | 0.09  | 0     | 0.13  | 0.35  |
| 3   | C              | 0.12  | 0.13  | 0.22  | 0.28  | 0.06  | 0.81  |
| 4   | D              | 1.17  | 4.79  | 3.59  | 2.59  | 1.71  | 13.85 |
| 5   | F              | 0.65  | 3.38  | 2.17  | 2.06  | 2.88  | 11.14 |
| 6   | G              | 5.94  | 9.14  | 2.85  | 4.24  | 4.76  | 26.93 |

Based on data received from external doses for Topaz management employees per year and 5 years (NBD 20 mSievert/year) is still below the permitted threshold[8]. To control this, it is necessary to limit the number of employees managing and processing Topaz stone products by changing officers with the time determined by the Radiation Protection Officer (RPO), so as to reduce the receipt of exposure. For the aspect of radiation protection to workers, all workers are required to use a ring-type TLD. This is because the closest activity to an irradiated object is the part of the hand. Noting that the Topaz sorting process is irradiated which allows the existence of fine dust that can enter through breathing. So that the management of Topaz stone must also take into account internal exposure, so workers are required to use filtered masks. Based on the results of the In-Vivo examination using the WBC examination, no radionuclide content was inhaled by radiation workers managing Topaz stones.

The use of PPE in addition to filtering masks, officers must also use a safety belt in taking Topaz stones from the reactor pool, this is to prevent accidents from slipping into the reactor pool. In the vicinity of the workplace also has been provided aids in the form of a rescue tire, if there is a worker slipping into the reactor pool.

4.2. Fulfillment of administrative aspects

Based on fulfilling the requirements according to the Head of BAPETEN Regulation No. 5 of 2016 article 2 paragraph 3 letter g, that Topaz stone irradiation can be produced by meeting the requirements listed in Chapter II article 6 paragraph 1[9].

These permit requirements are those that mandatory of the partner (PT. INUKI Persero) to obtain a production permit, with the requirements that the PRSG mandatory are:

a. floor plan of the Topaz stone storage;
b. drawing of Topaz stone irradiation facility design;
c. radiation protection and safety program for the production of consumer goods;
d. safety goods consumer verification report;
e. safety verification report on the production of consumer goods;
f. production protocol for handling pre-irradiated Topaz stones;
g. in-core position Topaz stone irradiation production protocol;
h. out-core Topaz stone irradiation production protocol;
i. production protocol for capturing Topaz after Irradiation;
j. irradiation production protocols;
k. Topaz irradiation SAR on 4 (four) IP positions in RSG;
l. calibration certificate of the instrument used;
m. the work program of the Quality Assurance Unit;

n. The topaz ID card and SIP manager;

o. the results of the evaluation of the receipt of dosages of workers managing Topaz stones;

p. annual radiation doses data; and

q. type and amount of radiation protection equipment, as well as Radionuclide data in Topaz stones.

Based on the fulfillment of these criteria, the PRSG has fulfilled these requirements and obtained BAPETEN permission to irradiate Topaz stones in Core position, with a permit for 2 (two) years with license number No 082591.073.11.290319 which will be evaluated periodically by BAPETEN.

4.3. Additional controls must be made

With the profile "B" in the safety profile assessment, some potential direct or delayed hazards that can be caused in the management of Topaz stones based on the contribution of dominant factors as well as additional controls that must be carried out are shown in Table 5. Additional controls that must be prioritized in receiving external exposure, physical danger, ergonomics and fatigue. Based on the data in Table 4, time and personnel restrictions must be made, in accordance with ALARA principles[10] based on Table 3, the biggest contribution is due to the opportunity for the risk to be given a value in number 5, this affects the total risk assessment value>25. For this reason, additional control is recommended in Table 5.

Table 5. Proposed additional controls to reduce potential hazards in managing Topaz irradiation

| No. | Potential hazard                        | Control that has been done                               | Additional controls to reduce potential hazards                                      |
|-----|----------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------|
| 1   | External exposure                      | PPE and administrative (procedure)                       | Evaluation of SOP, limitation of work time and replacement of personnel, and monitoring of PPR |
| 2   | Potential physical hazards (equipment dropped) | PPE and administrative (procedure)                       | SOP evaluation providing additional tools for the use of tools and measuring instruments so as not to fall into the pool |
| 3   | Physical hazards (the officer splashes into the reactor pool); | PPE and administrative (procedure)                       | SOP evaluation, the addition of mechanical lifting equipment and use of anti-slip shoes |
| 4   | Fatigue factor                         | PPE and administrative (procedure)                       | SOP evaluation, the addition of mechanical lifting equipment, reduced workload.     |

4.4. Local and export transportation requirements

Transportation requirements must be met by submission to BAPETEN. From the aspect of flight safety, the transportation permit and export permit for the irradiated Topaz stone are included in the category of dangerous goods (DG) or B3 material. With the issuance of production and transportation permits from BAPETEN the overall technical and administrative aspects have fulfilled the requirements of the International Air Transport Association (IATA). As for the Topaz stone export permit, it was issued from the Ministry of Energy and Mineral Resources. Permits issued are categorized as re-export permits, this is due to the initial material not originating from within the country.

5. Conclusion

Topaz irradiation management in the in-core position at GA Siwabessy meets the safe category and has obtained a production permit from BAPETEN. The value of the safety profile is achieved by effective control of the radiation safety risk profile, the use of PPE, compliance with administrative aspects such as BAPETEN permit requirements, re-export permits and international transportation.
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