Analysis of Irradiated Pebble Bed Fuel Transfer System in Hot Cell 101 Radiometallurgy Installation

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Abstract. As the operating body that has authority to construct and operate a non-commercial nuclear reactor in Indonesia, BATAN has decided to develop RDE, an HTGR based nuclear reactor with pebble bed fuels type. As the post-irradiation examination facility, IRM has to prepared and developed PIE for pebble bed fuel in hot cell. Mechanisms and supporting apparatus has to be considered during transfer processes from RDE sites to hot cell. This paper aims to analyze technical design of pebble bed fuel compatibility to existing transfer system in hot cell 101 such as wall-plug and transfer cask dimension, storage rack and fuel remote handling system. Several associated R&Ds on hot cell facility in HTGR countries are reviewed to get safer and simpler transfer system. Based on determined RDE fuels and wall plug dimension, RSG-GAS existing transfer cask can be adopted. Storage rack in hot cell 101 need to be modified and for easier handling by using manipulator, aids need to be added. The technical compatibility based on the results of the study indicates that the hot cell 101 is ready to execute PIE of RDE pebble bed fuels.

1. Introduction
Research and development related to High Temperature Gas-Cooled Reactor (HTGR) became one of the trends of today [1],[2]. Not only has the features and very high safety levels as a nuclear power plant, in parallel HTGR can also be used for many purposes, among which are quite popular are for the production of hydrogen and sea water desalination [2]. Based on the authority of the implementing body under Act No. 10 of 1997 to build and operate a research reactor in Indonesia, the National Nuclear Energy Agency (BATAN) decided to develop an HTGR-based Experimental Reactor (RDE). The RDE is being developed by BATAN, designed to have a thermal power of 10 MWth with a generated power of 2.9 MWe. To meet the internal operating needs, RDE requires only 13.8% of the generated power, so the power needs around the RDE area can be fulfilled from the power generated by RDE [3].

Radiometallurgy Installation (IRM) of the Center for Nuclear Fuel Technology (PTBBN) is designed to conduct post-irradiated testing of Pressurized Water Reactor (PWR) fuel, Pressurized Heavy Water Reactor (PHWR) fuel and Multipurpose GA-Siwabessy Reactor (RSG-GAS) fuel elements. In addition, post-irradiation examination is also performed on other reactor components such as refrigerant pipes and reactor vessels. Post irradiation examination was performed in hot cells and several other supporting laboratories. During this time, IRM has conducted post-irradiation
examination on RSG-GAS fuel elements with 2.9 g/cm$^3$ and 4.8 g/cm$^3$ uranium densities and also some candidate of fuel element structure materials [4]-[9]. The decision of BATAN to develop the RDE must be followed by IRM forwardness to conduct post-irradiation examination of RDE fuel as control and evaluation of fuel performance during the RDE operating period.

The type of RDE fuel candidate is pebble bed type which refers to the HTR-10 fuel design that differs in dimension and geometry to the fuel design accommodated by the IRM hot cell. Analysis to determine the addition and modification of equipment in IRM consisting of transfer equipment, test equipment and storage shall be carried out for each hot cell ranging from hot cell 101 to hot cell 112. Hot cell 101 is the entrance and the storage of post-irradiation nuclear fuel before examination. In post-irradiation examination stage, the suitability of receiving mechanism of post irradiation RDE fuel into hot cell and transfer system between hot cell plays a very important role. This study aims to analyze the suitability of post-irradiation RDE fuel receiving mechanism into hot cell 101 which includes cask transfer dimension, wall plug, handling system and temporary storage rack of post-irradiated nuclear fuel.

2. Pebble Bed Fuel and Post Irradiation Examination

2.1. HTGR Fuel
There are two concepts of fuel element shape that used in HTGR as shown in Figure 1. The first concept is pebble bed type initiated by Germany and Russia. This concept has recently been developed by China and South Africa. The second concept is prismatic fuel element block that is widely developed in the United States, Britain, Japan and Russia [3].

![Figure 1. HTGR fuels of pebble bed type and prismatic type][10]

The pebble bed type of HTGR has 60 mm of diameter with 50 mm of which is the area filled with about 10,000 pieces of TRISO particles, while in the 796 mm x 360 mm prismatic block type, 13,500 TRISO particles are compressed in rod and placed in 210 holes on prismatic blocks [3,9].

2.2. Radiometallurgy Installation
IRM is designed to carry out testing and development of pre- and post-irradiation examination on fuel elements of research and power reactors and also other reactor components. IRM is equipped with three large concrete hot cells (101, 102 and 103), seven small steel hot cells (104, 105, 106, 107, 108, 109 and 112) and two medium steel hot cells (110 and 111). To support the handling system during
the post-irradiation examination process in the hot cell, each hot cell is equipped with a manipulator with some of them equipped with a power manipulator and incell crane as a supporting tools. Transfer between hot cells using two conveyor lines. The function and description of each hot cells are shown in Table 1 and Figure 2.

### Table 1. Function of IRM hot cell [11]

| Hot Cell | Function |
|----------|----------|
| 101      | Entrance of nuclear fuel elements |
| 102      | Dismantling of nuclear fuel elements |
| 103      | Non-destructive testing |
| 104-107  | Preparation and observation of microstructures of nuclear fuel element samples |
| 108-109  | Physicochemical testing |
| 110-111  | Mechanical testing (fatigue test, tensile test, macrohardness test, blister test and impact test) |
| 112      | SEM/TEM preparation |

**Figure 2. IRM Hot Cell**

3. **Methodology**

   The first step to find out the readiness of IRM hot cell as the main support to know the performance of RDE fuel through post irradiation examination is by determine the suitability of technical data between RDE fuel with the receiving system in IRM hot cell. Compatibility analyzed includes fuel dimensions to fuel transfer cask commonly used for RSG-GAS fuel transfers and wall plug in hot plug 101 switches, temporary storage and handling tools at the transfer process from and to hot cell 101.

   In addition, a review of the current status of post-irradiation examination research and development in some HTGR developer countries was also undertaken to determine the receiving and handling methods of fuel which will be tested in hot cell, and also the strengthening of the test method to be used in the post-irradiation examination [12-15]. The results of the review are used as a recommendation when there is suitability and evaluation when there are some things to be modified.

4. **Result and Discussion**

   4.1. **RDE Fuel**

   The technical specifications of RDE fuel candidates to be used refer to HTR-10 fuel and are shown in Table 2.
| Part                  | Dimension (mm) |
|----------------------|----------------|
| Fuel spheres         | 60             |
| Graphite layer       | 5              |
| Coated Particle      | 0,92           |
| Kernel Uranium dioxide | 0,5           |

4.2. Receiving Line of Spent Fuel Elements

Hot cell 101 is the main fuel receiving line from RSG-GAS and sending the post-examination fuel elements to the Temporary Storage Installation of Used Fuel (IPS-B3). The current fuel element transport process has been accommodated by a connecting channel that connecting IRM with RSG-GAS and IPS-B3, so it does not involve landline, one of which is commonly used for transfer of Low Enriched Uranium (LEU)-Foil Target. The RDE site located outside the serpong nuclear area makes RDE fuel transportation process ascertain by landline as shown in Figure 3.

The receiving system in the transfer process involves equipment as shown in Figure 4. The transfer process begins by inserting the fuel element in the cask transfer in which there is a container containing spent fuel elements. Transfer cask are transported by transport vehicles to IRM through the entrance hall (EH-113). In the EH-113, transfer cask is set on an adjustable chassis that can adjust the transfer cask position to the wall plug in which there is a ball lock system mechanism in hot cell 101. The fuel element is ready to be transferred into hot cell 101 as the receiving hot cell. Based on dimension analysis, 100 mm container diameter can accommodate RDE fuel with 60 mm in diameter.
Figure 4. Fuel element transfer support system in IRM consisting of Ball Lock System and Adjustable Chassis (a); Transfer Cask (b); and Fuel Element Containers (c).

Receiving systems as part of the transfer system performed in IRM are not much different from other countries hot cells that perform post-irradiation examination. A ball lock system mechanism that aims to minimize the risk of exposure and contamination is also applied through a port docking system in hot cells developed in Finland and India as shown in Figure 5.

Figure 5. Mechanism of receiving fuel in Finland and Indian hot cells[13],[16]

4.3. Remote Handling System
Handling of radioactive material inside IRM hot cell one of them using manipulator. Besides handling spent fuel and other radioactive test materials, manipulators are also used in activities related to waste delivery, hot cell decontamination, repair of tools in hot cells, management of material storage locations etc. IRM uses manipulator with Master Slave type (MS) – a manipulator type A100 made by Hans Walischmiller Gmbh as shown in Figure 6.

Figure 6. IRM hot cell MS-Manipulator[20].
The receiving of RSG-GAS spent fuel in hot cell 101, manipulator function is very important, that is taking fuel from the container contained in the transfer cask in a horizontal position. Hot cell 101 is designed to accept used RSG-GAS fuel plates and PWR/PHWR fuel rod. The plates and rods can be accommodated with the width of the tread grip of the current palm of the manipulator clamp. RDE fuel of pebble bed type will cause difficulties when handled with the existing manipulator. This is due to the lack of contact between the RDE fuel and the manipulator clamp footprint. The MS-manipulator used in RMI allows the replacement of the clamp footprint without personnel intervention into the hot cell or removes the manipulator from the hot cell. Based on this, when handling RDE fuel in the form of a ball manipulator footprint should be replaced with a footprint known as the ball-tong manipulator as shown in Figure 7. This can facilitate the handling and minimize the risk of damage to the fuel before being tested after irradiation.

Figure 7. Ball-tong manipulator to handle spherical objects[12].

4.4. Hot Cell 101 Temporary Storage of Spent Fuel

Before the post-irradiation examination process, spent fuel is temporarily stored in hot cell 101 in a shelf. Potential criticality is considered in storage both in terms of numbers and positions although the potential for the occurrence of criticality very small. According to IRM’s Safety Analysis Report (LAK), U-235 mass must reach 52 kg with a diameter of 17 cm to reach critical condition. With enrichment approaching 20%, the critical mass assigned to RSG-GAS fuel is about 400 kg. RDE fuel has uranium enrichment almost equal to RSG-GAS fuel, which is 19.5%, so with the amount of U-235 1 gram/pebble [21], the criticality possibility becomes very small in hot cell 101 when storing and handling RDE fuel.

The current available storage shelves only accommodate spent fuel according to IRM’s initial design, ie RSG-GAS fuel and fuel rods for PWR/PHWR as shown in Fig. 8 (a). Modification or addition of storage rack for RDE type pebble bed fuel is required. The space available to the manipulator when picking up and putting RDE fuel off and into the rack should be considered in the design of the rack to be added. The shelf design can be as simple as 8 (b) or integrated with visual observation tools using a digital camera as shown in Figure 8 (c) [12].

Figure 8. Existing fuel storage rack at hot cell 101(a); and storage rack candidates for RDE fuel (b).
5. Conclusion
Based on the dimension-based compatibility analysis between pebble bed type nuclear fuel candidates for RDEs to hot cell 101 and support facilities in the fuel reception system it is concluded that technically IRM is ready to receive RDE fuel with some additions and modifications. The available transfer cask can accommodate the shape and size of RDE fuel candidates. For aids in handling nuclear fuel, the modification of the manipulator footprint into ball-tong type is needed. New storage shelf designs need to be added to accommodate ease of handling with manipulators and storage management.

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