Design Criteria of Instrumentation and Control in Fuel Handling System of RDE

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Abstract. The Experimental Power Reactor (RDE) is built based on HTGR technology with pebble fuel. The fuel handling system in the RDE is one of the major installations for the RDE to maintain in continuous operation without being shutdown. There are several stages in RDE fuel supply in its fuel handling system, first fresh fuel input stage, second fuel fuel field selection, and third used fuel selection which can still be used provided that it still meets degree burn / burn-up below 80% and become waste (spent fuel). These three processes need to be monitored and controlled with an integrated instrumentation system. The system is generally called the instrumentation and control system (I&C) fuel handling system To meet these needs it is necessary to design and construction the system required criteria with reference to several standards.

1. Introduction
In the development of Reactor Daya Experimental (RDE)[1] Pebble Bed Reactor (PBR) technology is chosen with the consideration of very safe, functioning for cogeneration, fuel flexibility, tested, competitive price, multipurpose, can be developed in all regions of Indonesia as needed, and to meet the needs of electricity supply. On the safety side, the passive safety system of the PBR design ensures a very minimum radiation release to the environment under any conditions including severe conditions such as those experienced in Fukushima accidents. The PBR design has an inherent safety system that relies only on natural mechanisms so that the reactor core system becomes very simple when compared to today's commercial nuclear reactor systems. The general schema of the RDE system is shown in figure 1.
Figure 1. Block diagram of Experimental Power Reactor (RDE)[2].

One part of the RDE designs being developed is the instrumentation and control system (SIK). The FHS (Fuel Handling System) RDE chart is shown in figure 2. In normal operation the fuel handling device is supplying fuel to the reactor core continuously replacing any fuel that exits from the reactor core through the fuel discharge tube. The working principle of the fuel handling system is as follows:

1. The fuel coming out of the reactor core through the fuel discharge tube will be examined physically (fragment test) by the failed fuel separator, this tool works by rotating so that the physically damaged fuels will be separated out through holes with diameter <60mm. Then spent and damaged fuel is stored in the failed fuel cask[3].

2. The fuel passing through the fragment test will be forwarded to the burn up measurement device. If the burn up value has not been reached or is still below 80%, the fuel is returned to the terrace with the help of the pneumatic system[4].

3. If the burning grade is more than 80%, spent fuel will be forwarded to the spent fuel shipping cask for disposal.

4. If the fuel burning value is not detected, then considered as a fuel dummy, the fuel dummy is required at the start of the reactor operation and firstly with a ratio of 50:50.

5. The ratio of fuel turnover in each cycle is 1:1 (one out-one in), with total replacement of new fuel is 25 fuel per day, and the remaining fuel is the value of the fuel fraction still qualified.
Figure 2. Block diagram of RDE fuel handling system[2].

Where, (1) Reactor pressure vessel, (7.1) Fresh fuel storage, (7.2) Burn up, (7.3) Fuel elevators, (7.4) Fuel separator, (7.5) Fuel storage damaged, (7.6) Dummy graphite fuel storage, (7.7) Used fuel storage.

2. Theory

2.1. Design Criteria[5]
Design criteria are the explicit goals that a project must achieve in order to be successful. In recommendation and feasibility reports, especially, the design and decision criteria determine the document's final recommendation for action. Managers use these criteria as their basic tool in evaluating a project's potential for success and how well it fits into the goals of the organization. Experts need explicit design and decision criteria in order to evaluate recommended designs of devices and test procedures. Design criteria can be divided into primary and secondary criteria. Primary criteria are those that constitute a successful project; the project will be unsuccessful if it does not meet these goals. Secondary criteria are those features that are highly desirable but not absolutely essential. Separating primary and secondary criteria establishes a clear hierarchy in design choices. Often, implementing one criterion makes the implementation of another infeasible or costly, or a secondary criterion may be sacrificed in favor of a primary criterion. Make the design criteria short but as specific as possible. Avoid vague language. List the primary criteria first; then list the secondary criteria. Often design criteria are best displayed in bulleted lists, with short titles preceding the explanation. These titles may then be used later in the document to refer to the specific criteria being discussed. If the criteria using number, avoid referring to them later solely by number, as it will make confuse the readers.

2.2. Standard and Codes
A standard consists of technical definitions and guidelines that function as instructions for designers/manufacturers and operators/users of equipment. Standards can run from a few pages to a few hundred pages and are written by professionals who serve on committees. Standards are considered voluntary because they are guidelines and not enforceable by law. A code is a standard that has been adopted by one or more governmental bodies and is enforceable by law.
2.3. Instrumentation and Control Architecture

Control system architecture depicts the architecture of the plant control systems and the interface among the systems required for overall operation of process plant. The required Control System is determined by the level of functionality, complexity and safety of a plant. This may comprise of process control system, safety instrumented system, HIPPS, fire and gas system, package unit control system. Control system architecture drawing shall also shows supervisory level equipment such as operators workstation, engineering workstation, HMI server, OPC server, historian server, control panel such as ESD panel (push button and lamp), fire and gas matrix and also network equipment. Control system architecture shall clearly define the locations, main locations, remote I/O locations, indoor/outdoor location, control room/building limit. The major control, Ethernet and communication cables are also shown and specified. The control system architecture is conceptual in nature and is used for specifying the requirements of the control system to the DCS Supplier. This drawing is provided as supporting documentation for the process control system requisition.

3. Methodology

To determine the design criteria, the following stages must be carried out: conducting literature studies related to the system which are identical with the system that we will design, identify the main functions and components of the system based on the results of the study, the process description document and the P & ID schematics. Identification and selection of required standards and codes. Reviewing the design criteria we have set. Finalization of the design

4. Results and Discussion

4.1. Design Criteria of I & C in Fuel Handling System (FHS)

In preparing the design criteria, it is required parameters and units to be measured as well as control parameters. Parameters and units in the RDE fuel handling system are: unit of temperature in °C (degrees celsius), unit of pressure in bar, unit of fuel, amount in fuel, unit of fuel burnup in % and unit of flow rate in Kg / s, with environmental conditions as follows¹:

- Average temperature: 17 °C - 35 °C
- Average humidity: 95%
- Earthquake: Designed to resist earthquake factor of 0.29-0.57g
- Operating Temperature: 250 °C
- Operating Pressure: 30 Bar

The selection of the technical specifications of instrumentation equipment in FHS follows the design criteria such as: Hazard Protection Philosophy, FHS Area goes into a dangerous area and is influenced by radiation, the safety and material standards must meet Category A. Noise Immunity & Over Voltage, Electronic instrumentation equipment shall meet RFI and EMI resistance in accordance with IEC 61000. This applies also to maintenance of radio communications. Electronic instrumentation equipment shall comply with resistance to excess voltage in accordance with IEC 61643. Integrated Control and Safety System (ICSS), FHS control and safety systems must be integrated into the main control room of RDE and integrated with other SIK systems. Emergency Shutdown System (ESD), The system's ability to perform emergency blackouts. Fire and Gas System (FGS), RDE FHS Area equipped with Fire and Gas System (FGS) according to API standards. Communication Infrastructure for networking among personnels and among FHS electronic equipment.
4.2. Standard and Code
Some standards and codes are used as a reference in determining the design criteria FHS SIK among them:

- IAEA-TECDOC-1198, Current Status and Future Development of Modular High Temperature Gas-Cooled Reactor Technology, IAEA, Vienna, February 2001.
- IAEA SSG-37, Instrumentation and Control Systems Software Important to Safety for Research Reactor.
- IAEA SSG-39, Design of Instrumentation and Control Systems for Nuclear Power Plants.
- IAEA NS-G-1.1, Software for Computer Based Systems Important to Safety in Nuclear Power Plants.
- IAEA NS-G-1.2, Safety Assessment and Verification for Nuclear Power Plants.
- IAEA NS-G-1.3, Instrumentation and Control Systems Important to Safety in Nuclear Power Plants.
- IEC 61508, Functional Safety of Electrical, Electronic and Programmable Electronic (E/E/PE) Safety-Related Systems.
- IEC 61513, Nuclear Power Plants – Instrumentation And Control for Systems Important to Safety – General Requirements for Systems.
- IEC 60880, Nuclear power plants – Instrumentation and control systems important.
- IEC TR 6100 ser., Electromagnetic Compatibility Requirements
- IEC 61504, Continuous Monitoring of Radiation

4.3. Field Instruments Criteria
Some of the instruments installed on the fuel handling installation are as follows: Pressure Measurement, mounted on a 30 bar gas pipe with a diameter of 3" (80 mm), equipped with a transmitter. Flow Measurement, mounted on a 30 bar gas pressure pipe with a temperature of 250 °C and a diameter of 3" (80 mm), equipped with a transmitter. Temperature Measurement, mounted on a 30 bar gas pressure pipe with a temperature of 250 °C and a diameter of 3" (80 mm), equipped with a transmitter. Control Valve, used in isolated valve on pressure pipe 30 bar with diameter 62 mm. Motorize Operating Valve (MOV), used as actuation on isolated valve on pressure pipe 30 bar with diameter 62 mm. Burn-up Measurement is used to measure burnup of RDE fuel after exit from reactor pressure vessel[6]. The instrument is mounted on a 30 bar pressure pipe with a temperature of 250 °C and a diameter of pipe is 62 mm. Radiation Monitoring is used to measure the rate of radiation exposure in the RDE fuel handling area, and the instrument is mounted on a building wall, which is equipped with a transmitter. Fuel Counting Measurement is used to measure the amount of RDE fuel burned through each pipe in the fuel handling system. The instrument is mounted on pipe with pressure of 30 bar, with a temperature of 250 °C and a diameter of pipe is 62 mm, a method of measurement using eddy current for non contact detection and equipped with a transmitter.

4.4. I & C Architecture and User Interface Criteria.
Basic design of instrumentation and control in fuel handling system of RDE show in figure 3. Based on the drawing, the instrumentation and control system are divided into the area of the instrument field, consisting of instruments for measuring several operating parameters. The instrument is equipped with a transmitter to transmit data to the operator's computer. The next area of the room panel consists of input and output modules, PLC controllers and data communications networks. The last area is the control room or operator room, which is divided into operator and supervisor. In the operator room there is an operating computer with displays provided the user interface to the operation and control parameters. Some parameters are: fuel counting measurement, burn up measurement, helium gas flow measurement, helium gas temperature and helium gas pressure. The user interface is provided with virtual buttons to perform actuation on some actuators, namely isolation valve, sleading valve, and pneumatic valve. The goal of the virtual buttons are to control the direction of RDE fuel in
the form of a ball. Basic design of user interface for monitoring and control of RDE fuel handling system show in figure 4.

**Figure 3.** Basic design of instrumentation and control in fuel handling system of RDE

**Figure 4.** Basic design of user interface for monitoring and control of RDE fuel handling system

4.5. **Other Supporting Criteria**

Instrument panel / cabinet is used for PLC, instrument distribution panel, and CCTV. Cables and junction boxes shall be compatible with requirement and required operating voltages. For example cable for signal, cable for non signal, cable with voltage 24 volt, etc. Cable with a large number of cores, its number of core must be greater than 20% of the required and meet the resilience to environmental conditions and resistant to radiation. The junction box should be made of 316SS material and should have a hinged cap with a 316 stainless steel retaining bolt, and a neoprene / cork
gasket. For small individual equipment/ instrument its box’s cover does not require hinged lid. Junction boxes must be certified. The junction box should have a removable hole (discharge hole) and should be able to accommodate a larger 20% of the specified number of cables. All junction boxes must meet the resilience to the environment and hazard areas of IP 66 and NEMA 4x certified minimum. Cable gland for electrical signal cables should be in double shell and stainless steel on gland heads connected with intrument boxes and junction boxes with NPT connectors. Cable gland must meet environmental and hazard resilience requirements. Cable tray is made of galvanized steel. The capacity of the cable tray must be greater than 20% of the actual capacity. Cable tray equipped with support on the structure of the building with enough power to sustain the weight of the cable tray following the cable inside. Tubing and fitting using a seamless SS material 316. The push gas pipe uses a 3 “ diameter with a seamless materil 316. The tubing joints, fittings and pipes use a special shell for helium gas and are resistant to radioactive material radiation. The earthing system is designed to meet the safety of equipment and maintenance personnel, signal integrity, and signal reference point when required. The earthing system of the instrument consists of grounding for instrument and staging signals for the instrument electrical system. Each instrument is tagged with identification with the equipment sign number. Tags must be permanent and rust resistant (stainless steel 316) with clear, sharp and readable description. The information displayed on the nameplate must include: number & title in uppercase, manufacturer name, model number, serial number, design code, pressure and temperature design, hydrostatic test pressure, MAWP (Maximum Workable Pressure) and year of manufacture. The identification tag is now securely attached to the instrument, i.e. field instruments, junction boxes, and panels.

5. Conclusion
The design criteria of instrumentation and control of the RDE has been determined with reference to the process document, piping & instrumentation diagram, and standard and code. Special instruments in FHS include burn up measurement, fuel counting measurement and radiation monitoring area. These design criteria look forward to be used as a reference in determining the qualification of the vendor at the time will be made fabrication and construction.

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