Internal fire probabilistic safety assessment preliminary work at research reactor TRIGA PUSPATI

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Abstract. An internal fire analysis Level-I probabilistic safety assessment (PSA) for TRIGA PUSPATI (RTP) nuclear research reactor was initiated. Previous study on half-scope mode Level-I PSA, focusing only on internal initiating event, were developed for both full power and shutdown operational mode. Hence, in ensuring PSA remains relevant, a subsequent study to kept PSA up to date is a compulsory. The aim of this study is to present the step-by-step work done and the insights gained in identifying and screening significant compartments that are potential to had the worst consequences as an ignition sources. This preliminary study will only focus on RTP’s basement which consist of 3 compartments: switch room, battery room and basement hall. Procedure in data collection were based on IAEA document, Specific Safety Guide No. 3: Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants (SSG-3). Microsoft Excel was used as data collection media and internal fire hazard database development. A brief qualitative analysis using failure mode and effect analysis is also presented.

1. Introduction
Probabilistic safety assessment (PSA) is a comprehensive structured approach to identify failure scenarios and to quantify estimation of risk and/or safety which describes accident sequences with the help of fault tree and event tree analyses [1], [2]. Figure 1 portrays three types of data needed in conducting a full scope PSA study, which are: (1) Internal events: data consists of random failure of systems or components or human error; (2) Internal hazards: data consists of internal fire or internal flood; and (3) External hazards: data consists of natural phenomenon or man-induced. Each of these data is further divided according to three reactor's operation modes: (1) Shutdown state; (2) Low power; and (3) Nominal power. The result of Level I PSA is core damage frequency (CDF), Level II, large early release frequency (LERF), and Level III, is radiological consequences.
PSA was introduced in the sixties as an ultimate safety assessment approach for space shuttle by National Aeronautics and Space Administration (NASA), when three astronauts were killed from the Apollo test AS-204 on January 27, 1967 [3]. Early applications of PSA on conventional nuclear power plant (NPP) was traced back in the United Kingdom (UK) [4] and the United Stated (US) [5] for their gas-cooled reactors (GCR’s) and light water reactors (LWR’s) respectively. Meanwhile, the application of PSA on nuclear research reactor was documented by the IAEA [6] as early as 1980.

In Malaysia, at the only nuclear research reactor been built, reactor TRIGA PUSPATI (RTP), an initial work in attempting to incorporate internal fire probabilistic safety assessment (PSA) into Level-I PSA model was implemented in early June 2019. Recently, the Malaysian PSA team developed a level 1 PSA focusing on random failure of systems, components and human error [7–11]. As per mention in Maskin et al. [9], Level-I PSA for RTP is a new adapted project which is develop without any official database.

The main purpose of this paper is to prepare necessary data in assessing internal fire hazard Level-I PSA. In particular, this paper aims at introducing a systematic approach in data collection and qualitative assessment throughout the process in preparing the necessary data. It is also intended to serve as a guide in a step-by-step guidelines for the development of fire PSA studies for a nuclear research reactor, as per recommendation by the IAEA [12], requirement 20, which is: “...The Level-I PSA for internal fire should be documented in a manner that facilitates review, applications and updating of the Level 1 PSA”. Finally, a success in this initial work, will be a result to expand the current study from only basement to the entire RTP building.

2. Methodology
An illustration of the adapted methodology is illustrated in Figure 2, showing two major process, which are: (1) Data collection; and (2) Qualitative analysis.

The scope of this study covers Level-I internal fire PSA, perform at full power and daily shutdown operational conditions (the shutdown for annual maintenance is not included in this study). Meanwhile, the location considered is focusing only at the reactor basement.
Figure 2. Data collection and qualitative analysis approach for fire PSA.

2.1. Data Collection

2.1.1. Plant walkdown. On preparation for Level-I fire PSA, a thorough plant walkdown is performed to verify information on fire hazard (potential ignitor) sources and plant features susceptible to damage due to fire hazard.

Familiarization of the plant, especially on the identification and how measurement need to be taken for compartment physical characteristics such as, boundaries (walls, doors, openings, etc.), cables route (conduits, trays, trunkings, etc.) is the key element in a fire PSA study. Fail to record precise information is a failure in simulating fire and smoke flow correctly. A walkdown sheet used in this study is partially depicted in Table 1.

Table 1. Walkdown sheet (partial)

| **Date:** | **Completed by:** |
|-----------|------------------|
| **Building:** | **Elevation /floor:** |
| **Room#:** | **Room name:** |

1. Compartment attributes

| Attribute | Comments / Quantity |
|-----------|-------------------|
| Area / Height (m², approximate or L x W) |
| Wall material / covering |
| Floor material / covering |
| Ceiling material / covering |
| HVAC system | Present |

2. Compartments openings (doors, access, HVAC, etc.)

| Opening | Location (X-Y or degree) | Height of Floor (m) | Opening Height (m) | Opening Width (m) | Open / Closed / Changes | Comments (note of doorway) |
2.1.2. Fire compartment identification. According to IAEA [13], in the context of a PSA for internal fires: “…a fire compartment could be a well-enclosed room that is not necessarily surrounded by fire resistant barriers”. Therefore, as illustrated in Figure 3, RTP basement is identified to have three compartments, consist of: (1) Switch room; (2) Battery room; and (3) Basement hall.

![Figure 3. Basement layout diagram (landscape)](image)

2.1.3. Fire compartment-components database. All information (recorded manually in Table 1), including the measurement of each physical characteristic (width, height, location), both boundaries and cables route were recorded systematically into an Excel database. This database is a living document and can be altered accordingly, based on additional important information.

The objective in developing such database is to quickly and accurately assess all relevant information related to the potential equipment failures for fire scenarios of interest, e.g. total failure of all circuits in a compartment, failure of cables within a specific raceway, impact of failures based on specific equipment failure modes etc.

2.1.4. Fire compartment drawings. Autodesk Inventor, a 2D and 3D mechanical design software is used (student’s licensed trial version). Four templates 3D view layout drawings for each compartment were developed. These layouts are consisting of: (1) Compartment openings; (2) Cables and trunkings, (3) Electrical cabinets; and (4) Fire suppression components, with exact measurement applied to all layouts. Later, a 2D drawings for the same four layouts in the 3D drawings mentioned above were developed, which mainly to determine the coordination location of each component.

2.2. Qualitative Analysis and Screening

2.2.1. Qualitative Analysis: Failure Mode and Effect Analysis (FMEA). An inductive analysis, FMEA to examine each system potential failure mode due to occurrence of fire. It may be loss of function, unwanted function, out-of-tolerance condition, or any related failure. The significance of a failure mode depends on how the system responses to the failure [14], [15]. Table 2 indicates designator failure mode for each component in the basement, together with an identification consequence on the system for each failure mode, if the component fails.

2.2.2. Qualitative Screening. Uniform approach is perform in qualitative screening to assign appropriate initiating event (IE) as depicted in Figure 4 [16].
Table 2. An independent failure mode and effect designator for component type

| Failure Mode  | Consequences / Effects                                      |
|---------------|------------------------------------------------------------|
| 1. Fail to start [FS] | 1. Lead to an initiating event (IE)                      |
| 2. No power supply [NP] | 2. Affect the ability of safety functions to mitigate an IE |
| 3. Operator action [OA] | 3. Affect operator actions after the occurrence of an IE   |
| 4. No signal [NS] | 4. Lead to spurious actuation of functions that could induce other unsafe effects |
| 5. Fire spark [FiS] |                                           |

Source: IAEA, pg. 72 [17].

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![Figure 4. Flowchart for qualitative screening](image)

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3. Results and Discussion

3.1. Data Collection and Drawings
Inaccurate data collection typically in measurement, may lead to invalid result and affect the outcome of a study. This is a valid lesson learnt whilst trying to merge inventor template files to form one complete compartment consist of 4 templates: (1) compartment openings; (2) cables and trunkings, (3) electrical cabinets; and (4) fire suppression components. Failing in merging the templates, stemmed in measuring the same compartment repeatedly. Figure 4a and 4b illustrated 2D drawing for switch room compartment openings and fire suppression systems respectively. Meanwhile, Figure 5 depicted a successful merged 3D drawing for switch room.
Drawings for RTP basement resulted with 51 template files for switch room, 23 template files for battery room and 212 template files for basement hall.

3.2. RTP Internal Fire Database Development

Figure 6 illustrate a screenshot of the developed internal fire database. As per stated earlier, this database is a living document which will be updated from time to time to reflects any current modification and component installation.
3.3. Failure Mode and Effect Analysis

Table 3 presents the lists of components with its failure mode and the consequences or effects to RTP if it fails.

| No. | Compartm | Failure Mode | Consequences or Effects | IE |
|-----|-----------|--------------|-------------------------|----|
| A.  | Switch room | Fire suppression: Heat detector | FS | Operator missing compelling signal/ annunciator after the occurrence of fire | No |
| 1.  | Fire suppression: Smoke detector | FS | Operator missing compelling signal/ annunciator after the occurrence of fire | No |
| 2.  | DB ‘RE’ | FiS | Lead to an initiating event (IE) | Yes |
| 3.  | DB ‘REB’ | FiS | Lead to an initiating event (IE) | Yes |
| 4.  | Main switchboard (MDB) | FiS | Lead to an initiating event (IE) | Yes |
| 5.  | DB ‘RNB’ | FiS | Lead to an initiating event (IE) | Yes |
| 6.  | TNB source | NP | Reactor blackout | |
| 7.  | Battery | NP | Reactor blackout | No |
| 8.  | Uninterruptable power supply (UPS) | NP | Reactor blackout | No |
| 9.  | Switchboard | FiS | Lead to an initiating event (IE) | |
| 10. | Fire suppression: Heat detector | FS | Operator missing compelling signal/ annunciator after the occurrence of fire | No |

Based on the initial FMEA screening analysis, the ‘Yes’ value indicated in Table 3 above, only shows one initiating event for both compartments, which is fire spark. However, this result will be re-evaluated based on which compartment has the worst fire consequences.

4. Conclusion

To have a typical and comprehensive PSA plant model, a complete list of representative IEs is essentially non-negligible. Incomplete consideration of IEs adversely affects the quality of a PSA, thus leading to results that underestimate the level of risk. Therefore, this preliminary study on the development of IEs for RTP internal fire is part of the effort towards fulfilling the completeness of a full scope Level-I PSA. This study has addressed both the systematic approach in data collection and qualitative assessment in preparing the necessary data for Fire PSA input. Finally, success in this initial work will be a result to expand the current study from just basement to the entire RTP building.

Data collection is the most crucial part of any study — failure to collect accurate data resulted in an incorrect result. Lesson learnt in a wrongly measured dimension stemmed in measuring the same
component repeatedly. However, despite the repetitive measurement, all 3D drawings for three compartments were successfully drawn and merged. At the same time, a compartment-component database that records all the plant walk-down sheet which reflects any current modification and component installation was developed as soon as the project starts. Meanwhile, from a qualitative assessment using inductive analysis, for all three compartments, only one IE was identified: fire spark.

Hence, our future works will be focused for the rest of the RTP’s building and proceed on the accident sequence modelling, and event tree development for the internal fire.

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