REACTOR TRIGA PUSPATI (RTP) SPENT FUEL POOL CONCEPTUAL DESIGN

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ABSTRACT

Reactor TRIGA PUSPATI (RTP) is the one and only research reactor in Malaysia that has been safely operated and maintained since 1982. In order to enhance technical capabilities and competencies especially in nuclear reactor engineering a feasibility study on RTP power upgrading was proposed to serve future needs for advance nuclear science and technology in the country with the capability of designing and develop reactor system. The need of a Spent Fuel Pool begins with the discharge of spent fuel elements from RTP for temporary storage that includes all activities related to the storage of fuel until it is either sent for reprocessed or sent for final disposal. To support RTP power upgrading there will be major RTP systems replacement such as reactor components and a new temporary storage pool for fuel elements. The spent fuel pool is needed for temporarily store the irradiated fuel elements to accommodate a new reactor core structure. Spent fuel management has always been one of the most important stages in the nuclear fuel cycle and considered among the most common problems to all countries with nuclear reactors. The output of this paper will provide sufficient information to show the Spent Fuel Pool can be design and build with the adequate and reasonable safety assurance to support newly upgraded TRIGA PUSPATI TRIGA Research Reactor.

Keywords: Spent Fuel Pool, Spent Fuel Pond, Spent Fuel.

INTRODUCTION

Since 1982, the Reactor TRIGA PUSPATI (RTP) has been safely operated and maintained by licensed reactor operators. It was designed to effectively implement the various fields of basic nuclear research and education. The PUSPATI TRIGA reactor uses solid fuel elements developed by General Atomic in homogeneous mixture of uranium zirconium hydride alloy containing about 8.5%, 12% and 20% by weight of uranium enriched to 20% U^{235} and RTP currently has 114 fuel elements for Core 14.

The spent fuel management has always been one of the most important stages in the nuclear fuel cycle. Even though RTP has not yet generating any spent fuels but there is a need for spent fuel storage facility. In support for the RTP power upgrading spent fuel facility is needed in order to transfer the entire fuel element from the reactor core to spent fuel pool to allow the new core structure to be placed inside the reactor tank for temporary storage of the irradiated fuel elements.

PROBLEM STATEMENT

After nuclear reactor is shutdown its nuclear fuel or so called neutron irradiated fuel will continuously produce heat from radioactive decay. Fuel elements that have been utilized in the reactor will be highly radioactive and will contain radioactive fission products that are retain in the fuel stainless steel cladding.

The handling and storage of the irradiated or spent fuel elements is the most crucial process where the highest safety aspects have to be considered such as damage of the fuel element itself, ensure subcriticality, ALARA in radiation protection and adequate decay heat removal. To ensure that the integrity of the fuel element and subcriticality are maintained, irradiated fuel should be handled, stored and inspected in approved spent fuel storage facilities by competent personnel and with tools and equipment that are certified for this purpose.

OBJECTIVE

i. The purpose of this project is to provide details on the design of interim spent fuel storage facilities. Such guidance is required to define and control the extent and quality of the facility, and will be used in preparing technical documentation.
ii. Good design is crucial to the safe operation of spent fuel storage facilities because spent fuel must be received, handled, stored and retrieved without undue risk to health and safety, or to the environment. To achieve this, the design shall incorporate features which will be effective for the lifetime of the facility under normal operating conditions, anticipated operational occurrences and design basis accident conditions in maintaining fuel subcritical, removing spent fuel residual heat, providing radiation protection and maintaining containment of radioactive material.

METHODOLOGY

Interim spent fuel storage facilities provide for the safe, stable and secure storage of spent fuel before it is reprocessed or disposed of as radioactive waste. Like other engineered systems, the safe operation and maintenance of spent fuel storage facilities depends in part on adequate design and construction. The most important design features of such facilities are those which provide the necessary assurances that spent fuel can be received, handled, stored and retrieved without undue risk to health and safety, or to the environment.

i. DESIGN PROCESS

In the design process, appropriate analytical methods, procedures and tools should be used in conjunction with suitably selected input data and assumptions for both normal operational states and credible deviations. Only verified methods are acceptable for predicting the consequences of operational states and design basis accidents. Similarly, input data should be selected so as to be conservative and these data should address both the normal and abnormal states of operation.

ii. SUBCRICALITY

The subcriticality of fuel may be ensured or influenced by a number of design factors and precautions. The physical layout and arrangement of the spent fuel storage facility shall ensure, through geometrically safe configurations, that subcriticality will be maintained during operational states and accident conditions. Where spent fuel cannot be maintained subcritical through configuration alone, the design shall specify additional means, such as fixed neutron absorbers or the use of a credit for burnup, to ensure subcriticality.

When calculating the infinite multiplication factor, which may be used as a conservative estimate of k_{eff}, the following rules shall be adhered to:

a) An adequate subcriticality margin shall be maintained which is acceptable to the Regulatory Body. Typically a 5% margin after inclusion of the uncertainties in the calculations and data is considered acceptable.
b) If the enrichment within individual fuel assemblies is variable, exact modeling shall be used or a pessimistically calculated, representative enrichment of the fuel assembly shall be assumed.
c) If the enrichment of the fuel assemblies differs, the design of the facility should generally be based on the enrichment value corresponding to that of the maxi-mum enriched fuel assembly. However, in situations involving only small amounts of fuel of higher enrichment, assessments may be made on a case by case basis taking into account the specific parameters of the fuel in question.
d) Where uncertainties exist in any data relating to the fuel (design geometries, nuclear data, etc.) representative values which are pessimistically calculated should be used in

all subcriticality calculations. If necessary, sensitivity analysis should be performed to quantify the effects of such uncertainties.

e) Neutron reflection shall be considered.

f) The inventory of the storage facility shall be assumed to be at the maximum capacity of the design.

g) Consideration of the neutron absorbing characteristics of the fuel assembly may be included.

h) Geometric deformations to the fuel and storage equipment which might be caused by any postulated initiating events shall be taken into account.

i) Appropriate moderation should be assumed for anticipated operational occurrences.

j) All fuel shall be assumed to be at a burnup and applicable enrichment value resulting in maximum reactivity.

iii. STRUCTURE AND LAYOUT

Design requirements associated with the layout of irradiated fuel handling and spent fuel storage systems are as follows:

(a) Handling and storage areas for irradiated fuel shall be secure against unauthorized access or unauthorized removal of fuel.

(b) The area used for storage shall not be part of an access route to other operating areas.

(c) The transport routes for handling should be as direct and short as practical so as to avoid the need for complex or unnecessary moving and handling operations.

(d) The layout shall reflect application of the ALARA ('as low as reasonably achievable') principle regarding all fuel handling operations, storage and required personnel access.

(e) The layout shall provide for decontamination and appropriate maintenance of fuel handling equipment and shipping casks.

(f) Space shall be provided, if necessary, to permit the inspection of fuel and fuel handling equipment.

(g) Space shall be provided to allow the required movement of the fuel and storage containers and the transfer of these between different handling equipment.

(h) Space shall be provided for the safe handling of a shipping cask. This can be achieved by using a separate cask unloading area or by including dedicated space within the facility.

(i) Space should be provided for the storage and use of the tools and equipment necessary for the repair and testing of storage components. Space for the receipt of other radioactive parts may also be required.

(j) Appropriate arrangements for containment measures and the safe storage of leaking or damaged fuel shall be provided.

(k) The layout shall provide easy exit for personnel in an emergency.

The design shall permit access to all parts of the storage facility requiring periodic inspection and maintenance.

iv. RADIATION PROTECTION

Radiation Protection Objective: To ensure that in all operational states radiation exposure within the installation or due to any planned release of radioactive material from the installation is kept below prescribed limits and as low as reasonably achievable, and to ensure mitigation of the radiological consequences of any accidents.
The basis of the operational radiological protection programme is set of measures aimed at reducing radiation hazards and radiation doses. It includes:

- *Incorporating adequate design features;*
- *Imposing restrictions in operating procedures;*
- *Applying extensive monitoring system for radiation and contamination;*
- *Ensuring adequate training of reactor personnel*

v. CONTAINMENT OF RADIOACTIVE MATERIALS

The design of spent fuel storage and handling systems shall provide adequate and appropriate measures for containing radioactive materials so as to prevent uncontrolled release to the environment. The spent fuel cladding shall be protected during storage against degradation that leads to gross ruptures, or the fuel shall otherwise be contained in such a manner that degradation of the fuel during storage will not pose operational safety problems.

Ventilation and off-gas systems should be provided where necessary to ensure containment of airborne radioactive particulate materials during operational states and accident conditions. All spent fuel storage containment systems shall be provided with monitoring to enable the licensee to determine when corrective action is needed to maintain safe storage conditions.

vi. HEAT REMOVAL

Spent fuel storage facilities is designed with heat removal systems capable of cooling stored fuel when that fuel is initially loaded into the facility. The heat removal capability shall be such that the temperature of all fuel (and fuel cladding) in a storage facility does not exceed the maximum temperature recommended or approved by the Regulatory Body for the type and condition of fuel to be stored. The heat removal system shall be designed to withstand all design basis accidents.

The design of heat removal systems for spent fuel storage facilities should include any appropriate provisions to maintain fuel temperatures at acceptable limits during the transfer of fuel.

vii. MATERIAL SELECTION

The design of a facility for the storage of spent fuel will be based upon a specified operational lifetime. This design life should include provision for routine inspection, refurbishment and replacement of parts. Safety related components of a spent fuel storage facility are designed to preserve their function during the lifetime of the facility. Where this is not possible, the design shall allow for the safe replacement of such components. The selection of structural materials and welding methods shall be based upon codes and standards acceptable to the internal safety committee. Consideration shall be given to the potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields.

The materials of structures and components in direct contact with the spent fuel assemblies shall be compatible with the fuel assemblies and shall not contaminate the fuel with foreign matter which might significantly degrade the integrity of the fuel during storage. The effects of corrosive agents inside and outside the spent fuel containment (e.g. on fuel cladding, water pool structure, cask, tank wall and ceiling) shall be considered. All systems shall have adequate reliability over the design lifetime commensurate with the radiological consequence of their failure.

viii. HANDLING

Spent fuel handling and transfer equipment and systems might include:

- Fuel handling machines;
- Fuel transfer equipment;
- Fuel lifting devices;
- Handling devices for all operations associated with transport containers;
- Provision for the safe handling of defective or damaged fuel or containers.

Handling equipment shall be designed to minimize the potential for damage to fuel, fuel assemblies, and to storage or transport containers. The design of spent fuel handling equipment shall include provision for the related use of portable manual or power operated tools, provided that the planned use of such tools is consistent with the design objectives and that such use shall not compromise the safety of the fuel handling operations.

ix. SAFEGUARDS AND PHYSICAL PROTECTION

The design of a spent fuel storage facility and its relevant systems should take account of safeguards and related requirements for physical protection, and should facilitate their resolution.

'Safeguards' refers to the IAEA safeguards system, the objective of which is the timely *detection* of any diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons, other nuclear explosive devices, or for purposes unknown, and *deterrence* of such diversion by the likelihood of early detection.

The design of spent fuel handling and storage systems and areas shall facilitate the application and maintenance of safeguards requirements as determined by the respective

Safeguards Agreements. This design shall provide for the installation, operation and maintenance of appropriate equipment and systems to establish and maintain a safeguards system consisting of adequate elements of physical protection, containment, surveillance and nuclear materials control and accountancy.

Physical protection arrangements which permit access only to authorized personnel shall be provided in order to deter and detect unauthorized access to storage structures or to areas where irradiated fuel is handled or stored. The design of spent fuel storage facilities shall include measures or systems to detect and deter any unauthorized diversion of nuclear materials from spent fuel handling and storage areas.

OPERATIONAL AND MAINTENANCE ASPECTS

The major requirement to be met immediately after a fuel element is discharged from the reactor core is to maintain its integrity, ensuring that it is properly cooled. Spent fuel cooling is necessary in order to remove the heat produced by the decay of the unstable fission products accumulated within the fuel element, which is a result of the fission process. Removal of the decay heat is necessary to avoid any possible spent fuel blistering, which could arise if the spent fuel were not properly cooled. In research reactors, appropriate cooling can be easily maintained by introducing the spent fuel into a decay pool, either connected to or adjacent to the reactor pool, located at the reactor site.

During this phase of the spent fuel management programme the following aspect must be addressed:

iii. Maintenance of optimum water chemistry for the cladding in question, and compatibility of materials

iv. Maintenance of optimum water chemistry is necessary in order to avoid fuel cladding degradation that occurs due to the existence of mechanisms that cause corrosion of the fuel cladding when in contact with water.

(1) Water Conditions

Conditivity : 10μS/cm
pH : 5.0 ~ 7.5
Radioactivity : 3.7 Bq/cm³

(2) Purification System

Operation : Daily?/Weekly?
Flow rate : 6 m³/h
Ability : 10μS/cm at outlet of Ion exchanger
Purification Capacity of ion exchange resin
: About 1,500 m³/batch

Maintenance of good water quality, and low temperature, reduces the rate at which the corrosion process occurs. Materials compatibility is also an important issue in operational storage because the contact of different metals within an aqueous medium causes galvanic corrosion of the metal with lower galvanic potential. In particular, contact between aluminium cladding and any other metal with higher galvanic potential, such as stainless steel racks or pool liners, causes localized galvanic corrosion of the aluminium cladding that can propagate and eventually expose the fuel meat, with consequent release of fission products.

For the reasons mentioned above, the need for maintenance of operational spent fuel management strategy is easily understood, and the main issues that should be taken into account in this phase of the spent fuel storage are as follows:

i. To properly remove the decay heat produced by the fission products accumulated within the fuel element.
ii. Water chemistry shall be controlled in order to guarantee the spent fuel cladding integrity throughout the planned periods of wet storage.
iii. Materials compatibility shall be taken into account because different materials will be present in the operational wet storage pool, depending on the construction materials used. In particular, contact between cladding and any dissimilar metal, such as stainless steel racks or pool liners, should be avoided.

SPENT FUEL POOL PROPOSED SPECIFICATION

Proposed Specification	
Dimension	Length 4.5m, Width 3.0m, Depth 6.5 m
Depth of Water	6.35 m
Volume of Water	87.75 m^3
Capacity of Spent Fuel (Rack – to be design)	130 elements (8.5% , 12% & 20% TRIGA type) 7x7 elements × 3 rack = 147 FE
Equipment	Spent fuel handling tools, Water level indicator, Water temperature indicator, Purification system

Table 1: Spent fuel pool specification

CONCEPTUAL DESIGN OF SPENT FUEL POOL

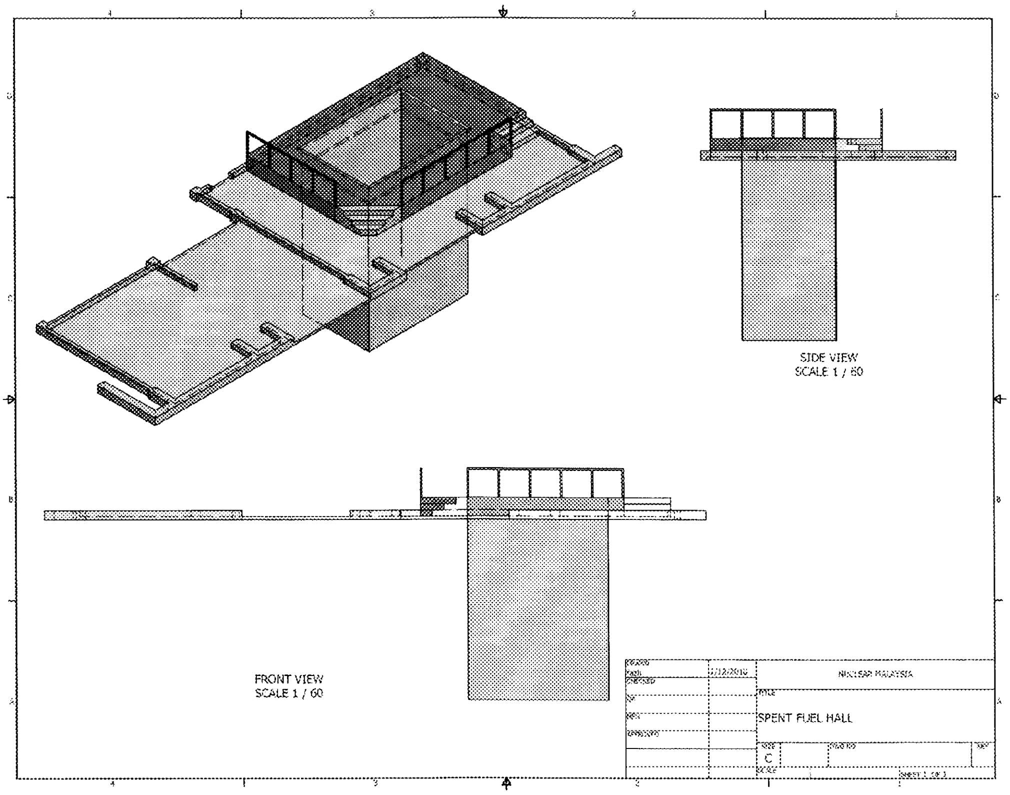

Figure 1: Spent fuel pool layout

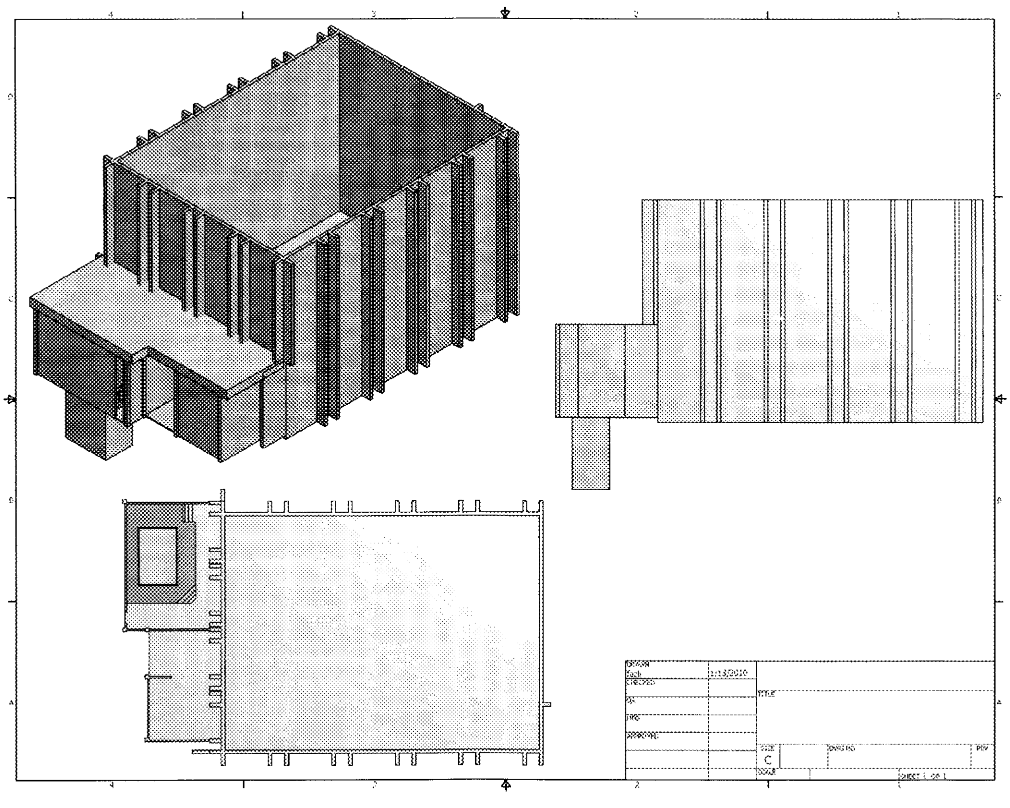

Figure 2: Extended reactor building layout

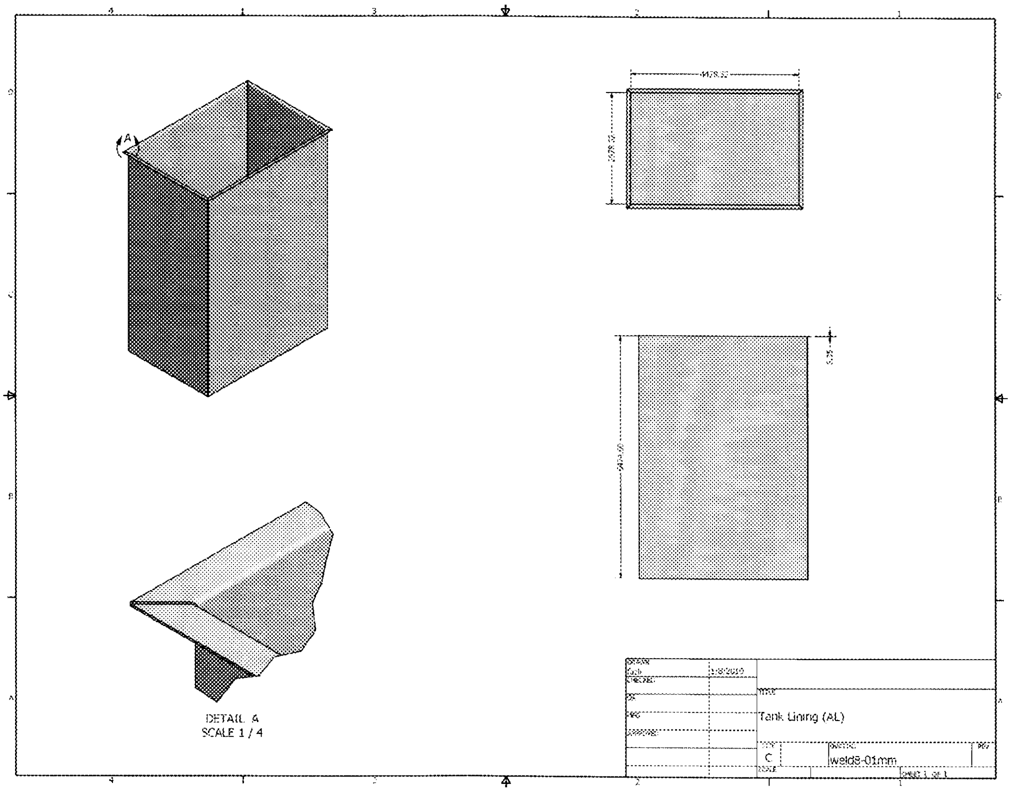

Figure 3: Tank lining

CONCLUSION

For research reactors that have only a few exceptions, wet storage is the most common strategy currently used for temporary storage of spent or irradiated fuels. Critical assemblies and very low power reactors generate small quantities of spent fuel, and have lifetime cores; consequently, dry storage for their irradiated fuel is currently the option used.

At the present time, the facilities available to store spent fuel at RTP consist of storage racks located in the same reactor pool, in a decay area adjacent to the reactor. The racks, with a total capacity to store only 30 fuel elements, at present, 27 storage positions are occupied, and 24 are required to store the fuel used in the reactor core in the case of emergency unloading, which means that only 3 positions are available for new spent fuel element removed from the reactor core.

Due to the low nominal power and short operation cycles, the research reactors TRIGA PUPSATI (1000 kW) at Nuclear Malaysia do not generate spent fuel but in order to support RTP power upgrading in the future the spent fuel storage facility is a must.

REFERENCE

i. ***Safety Requirements for Shielding Design of Research Reactors***, A. M. Shokr, Research Reactor Safety Section, Division of Nuclear Installation Safety IAEA, May 2010

ii. ***Shielding Issues for Power Upgrade of PUSPATI Research Reactor,*** A. M. Shokr, Research Reactor Safety Section, Division of Nuclear Installation Safety IAEA, May 2010

iii. ***Spent fuel management options for research reactors in Latin America***, IAEA, IAEA-TECDOC-1508, June 2006

iv. ***Design of Spent Fuel Storage Facilities,*** Safety Series No. 16, IAEA 1994