CHAPTER 1

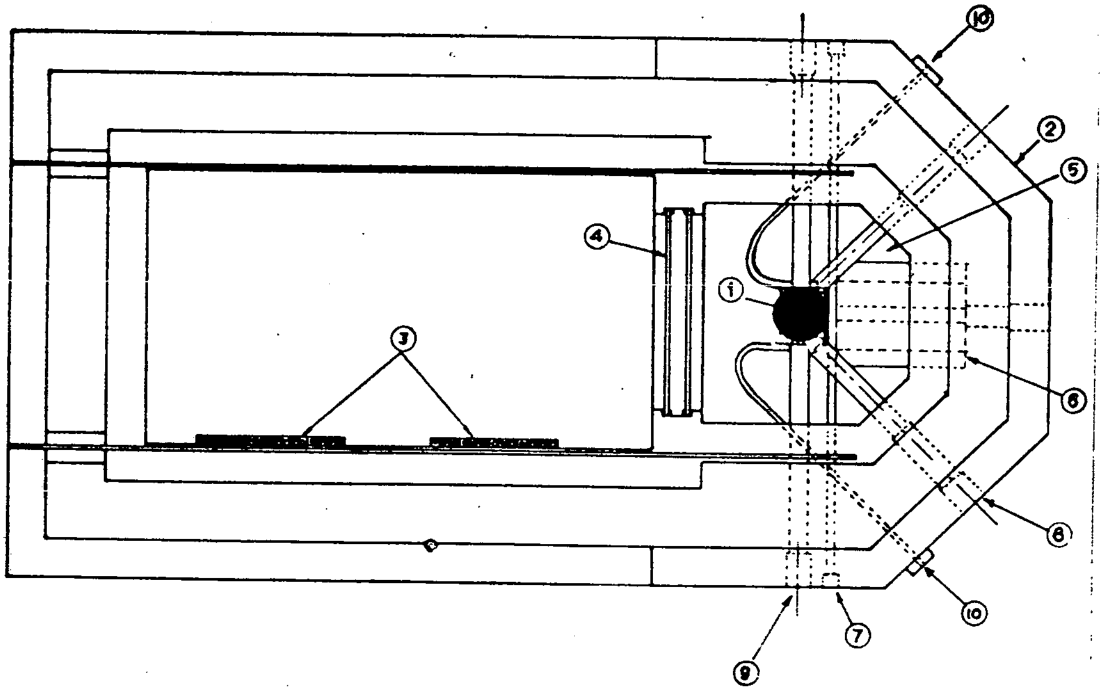
INTRODUCTION

1.1 Reactor Design and Core Geometry

The TRR-1 (an acronym of "Thai Research Reactor-1") was the first Thai Research Reactor, situated at the Office of Atomic Energy for Peace (OAEP), Bangkok . It was a light water moderated and cooled using HEU plate-type fuel with U_3O_8-Al fuel meat and a swimming pool tank. The reactor was built by Curtiss Wright Corporation at Quehann Pensylvania. It went Critical on October 27, 1962 and had been licensed to operate at 1 MW(thermal) with the total released energy of more than 482.46 MWd before being shutdown on June 30, 1975. The Core and control system was disassembled and replaced by that of a TRIGA Mark III type while the pool cooling system, irradiation facilities and others were kept the same. Thus the name "TRR-1/M1"has been used due to this modification.

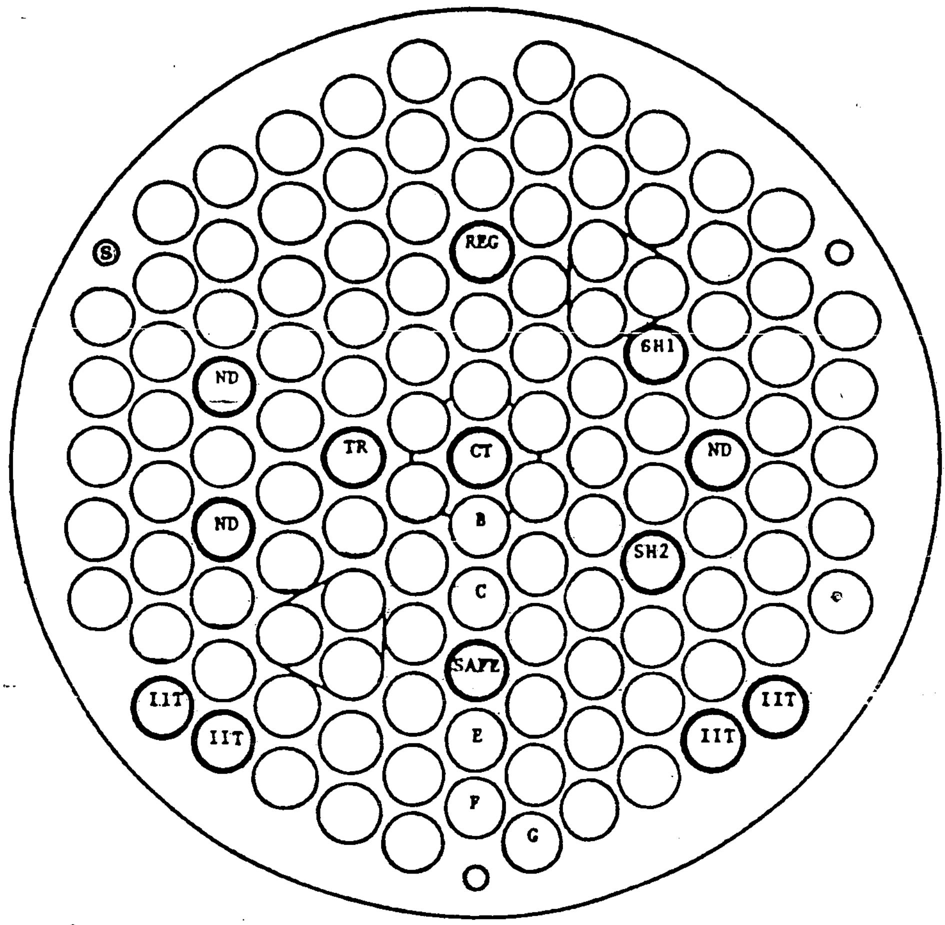
For orientation purposes, horizontal cross sections and core diagram of the TRR-1/M1 are shown in Fig 1.1 and Fig 1.2

The modification was made by converting to a standard TRIGA mark III design using Uranium Zirconium hydride (UZrH). Low Enriched Uranium (LEU) fuel with 8.5 wt. % Uranium. It is light water cooled, moderated and reflected.



1. Reactor core
2. Heavy concrete
3. Fuel rack
4. Water gate
5. Reactor pool
6. Thermal Column
7. Beam Tube 2"
8. Beam Tube 6"
9. Beam Tube 8"
10. Pneumatic Tube

Fig. 1.1 Horizontal cross section of the TRR-1/M1



CT : Central Thimble
ND : Neutron Detectors
IIT : Incore Irradiation Tubes

TR : Transient Rod
REG : Regulating Rod
SHIM1,2 : Shim Rods
SAFE : Safety Rod

Fig. 1.2 Core diagram of the TRR-1/M1

The TRR-1/M1 went critical on November 7, 1977 with the fresh initial critical mass of 2697.06 grams of U-235 which is equivalent to total of 67 elements of 8.5 wt.% LEU TRIGA fuel, including 4 Fuel Follower Control Rods (FFCR). The fuel elements were loaded for core loading No 1. Since 1980, 20 wt. % LEU fuel elements have been inserted to cope with higher core excess requirement resulting in mixed-core operation of the TRR-1/M1.

The TRR-1/M1 can be operated in three modes, steady state, square wave, and pulsed.First, steady state mode having maximum capacity of 2 MW (thermal). Now it is operated at 1 MW due to the limitation of the old heat exchanger capacity. Secondly, square wave mode, also having maximum capacity of 2 MW. The third mode of operation is pulsed mode, by step reactivity insertions with the reactor initially at a power level less than 1 kw. The maximum step reactivity insertion allowable is at 2.1 % $\delta k/k$ (\$ 3.00) which will produce a peak power of approximately 2,000 MW (thermal)

The TRR-1/M1 has been operated for more than nine years with the total released energy of 337.75* MWd. There has been four core configurations (core loading diagram) arranged since 1977. The current core is fifth loading configuration or core loading No.5. It contains two types of LEU fuel totally 112 elements, (94 Standard Fuel Elements, 4 Fuel Follower Control Rods with 8.5 wt. % U and 14 Standard Fuel elements with 20 wt. % U). All of new 14 LEU 20 wt. % U fuel elements are loaded in D-ring.

---

*Data measured on March 3, 1986 (Core No.5)

1.2 Previous-study

1.2.1 General Fuel Management

In general, nuclear fuel management encompasses the whole gamut of economic, technical, scheduling decisions including nuclear fuel material from ore procurement to radioactive waste burial. The fuel management concerning manipulation of the fuel in the core is referred to as core management.

1.2.2 Research Reactors Core Fuel Management

For Research Reactor core management is slightly different from those for Power Reactors due to the different objectives and utilizations. The fuel core management for research and power reactors comparison are clearly delineated in Table 1.1

In general, the performance of core management analyses on research reactors is less restrictive than on power reactors. In research reactors core management is concerned principally with the reactivity behavior of the reactor, whereas in power reactors core management deals with the reactivity behavior, the enrichment and the power distribution.

Table 1.1 Power and Research Reactor Differences Pertinent to a Fuel Management Program (1)

	Power Reactors	Research Reactors
Operations	Required Thermal Output	High Flux Intensities for Variety of Experiments
Fuel Enrichment	Variable; Depends on Previous Cycle	Usually Fixed
Power Distribution	Designed Near Maximum Allowable Peak to Average Power Ratio	Flexible to Permit Variety of in core Experiments
Refueling	Usually Fixed; Annual; Substantial Down Time	Very Flexible Anytime; Few Hours

Previous works concerning the fuel core management for the TRIGA Research Reactors are as follows

In September, 1972 W.F. Naughton (1,2)established the TRIGA Core Management Model (TRICOM) for used in the Pensylvania State Breazeale Nuclear Reactor (PSBR) by utilizing three basic types of information, (a) k-effective as a function of burnup, (b) relative changes in power fraction of fuel elements as a function of core burnup and (c) reactivity worth curves for fissile isotopes and neutron absorbers. His work resulted in the fuel management program substantially reduced the fuel cost and maximized the fuel utilization.

The model can predict the change of reactivity caused by the variation of fuel mass due to fuel burnup and / or replacing the 8.5 wt. % U fuel with 12 wt. % U fuel or vice versa. Naughton's study was not included the FLIP fuel (Fuel Life time Improved Program).

The PSBR is a 1 MW TRIGA Mark III reactor (original core was MTR type). It contains 90-element hexagonal array and composes of five smaller rings surrounding a central thimble containing water. The rings running from the center outward are designated B,C,D, E and F (A is a Central Thimble) respectively, and are composed of 6, 12, 18, 24 and 30 elements, respectively.

A normal fuel cycle for the PSBR of operating at BOC(Beginning of Cycle) core having a k-eff = 1.049 and depleting the fuel until an EOC(End of cycle) k-eff = 1.030 was attained. In each case, the k-eff corresponded a clean core at cold shutdown. This EOC k-eff value was just sufficient exess reactivity in the core to permit normal reactor operation at 1 MW during the week. Since this value was not sufficient to override equilibrium xenon at 1 MW, such that k-eff value was the point at which refueling should be taken place.

Two schemes had been analyzed and compared, by refueling with 8.5 wt. % U and / or with 12 wt. % U have more advantages than replacing with 8.5 wt. % U. The scheme was performed by refueling the six new 12 wt. % U fuel elements to replace the burnup 8.5 wt.% U fuel in the B-ring; and the core was rearranged such that the core contains decreasing U-235 mass arrangement outward from the core center.

Such scheme greatly reduced the cost of refueling schemes compared with refueling of 8.5 wt. U fuel.

In December, 1972 M.J. Cenko (3) had studied and compared the PSBR Operation's history with the TRIGA Core Management Model. No techniques were devised other than developing the computer code in the model.

In June, 1974 J.A. Easly (4) utilized Perturbation Theory in developing the Core Management Model established by Naughton, to obtain the reactivity worth curves instead of those obtained from Diffusion Theory as in Naughton's studies.

In December, 1983 Shen Li (5) modified the PSBR Core Management Model to be used with Microcomputer. Two reactivity worth curves can be used, one from Diffusion Theory another from Perturbation Theory (Naughton's and Easly's curves, respectively).

1.3 Specific Statement of the Problem

The OAEP is plan to upgrade the performance of the TRR-1/M1 includes replacing all of 8.5 wt.% LEU fuel with 20 wt.% LEU fuel in order to improve the fuel economy. The replacement will be done gradually as new fuels are needed. Since the TRR-1/M1 was in operation in 1977, the first fuel manipulation was performed in 1980 by inserting five LEU elements with 20 wt. % into the C-ring and rearranged the existent fuel to set up a new core configuration (Core No.2). Core No. 3 was slightly different from core No.2, by discharging the element in B1 and replaced with the element from C1 , G2 was transferred to C1 and left G2 empty. The subsequent refueling were in core No.4 and core No. 5, by inserting the four and five new 20 wt. % LEU elements, respectively. For core No.5, rearranged all 20 wt. % LEU elements were loaded in the D-ring in order to avoid the overheat problem in the 20 wt. % LEU elements, while maintaining flux level and distribution at various irradiation facilities.

The previous refueling were done based on increased reactivity requirements for radioisotope production. However, the refueling scheme of each core was decided based on the past estimates of remaining U-235 in each element, estimated flux distribution and average burnup factor at each respective ring (1.3 gm per MWd at all rings). Therefore, one could not predict the initial core excess, core life and number of available MWd's. Hence, the existing problems for fuel and core management can be summarized as follows.

- Lack of systematic method in rearranging the fuel elements in the core.

- The remaining U-235 content in each element could not be known exactly which is very important information in rearranging the fuel elements

- Lack of reactor calculation capabilities both personel and equipment in order to determine the Beginning of Cycle (BOC) and End of Cycle (EOC) excess reactivities.

Therefore, it is essential to develop reactor calculations capability in order to alleviate the lackings stated above. Thus, the specific purpose of this study are

(1) to provide calculated data that will assist in establishing a safe and economical fuel management strategy for the core conversion of 8.5 wt. % U fuel to 20 wt.% U fuel,

(2) to minimize the fuel costs by maximizing utilization of the existing inventory, and

(3) to provide information that may be helpful in planning of timely purchase of new 20 wt. % U fuel elements.