UTILIZATION OF THE THAI RESEARCH REACTOR (TRR-1/M1)

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1. INTRODUCTION

The Thai Research Reactor-1/Modification 1 (TRR-1/M1) is currently under the responsibility of the Thailand Institute of Nuclear Technology (TINT). After its first criticality in October 1977, the reactor has been utilized for a wide variety of applications. It is also the only research reactor in Thailand and has served as the largest neutron source for many users. This paper provides information describing TRR-1/M1, its operation, maintenance, fuel management programme and current utilization.

2. DESCRIPTION OF TRR-1/M1

The TRR-1/M1 is an open pool type TRIGA Mark III reactor with a concrete biological shield and four neutron beam tubes [1]. Historically, the reactor was built as an MTR type research reactor and it was named as Thailand Research Reactor 1 (TRR-1). The reactor had been operated since 1962 until 1975, when it was converted to the TRIGA type research reactor. In the conversion, the highly enriched uranium fuel plates were replaced by low enriched uranium fuel rods designed and supplied by General Atomics. In addition, the control system and the safety features were also replaced so that TRR-1 became essentially a TRIGA reactor. The reactor was then renamed as Thai Research Reactor-1/Modification 1 (TRR-1/M1) to reflect this conversion. After successfully achieving its first criticality in October 1977, routine operation of TRR-1/M1 began in November 1977. The TRR-1/M1 is licensed for2 MW, and core cooling is provided by natural circulation of pool water, which is in turn cooled and purified in external coolant circuits. Figure 1. presents the perspective and top views of the TRR-1/M1 structures.

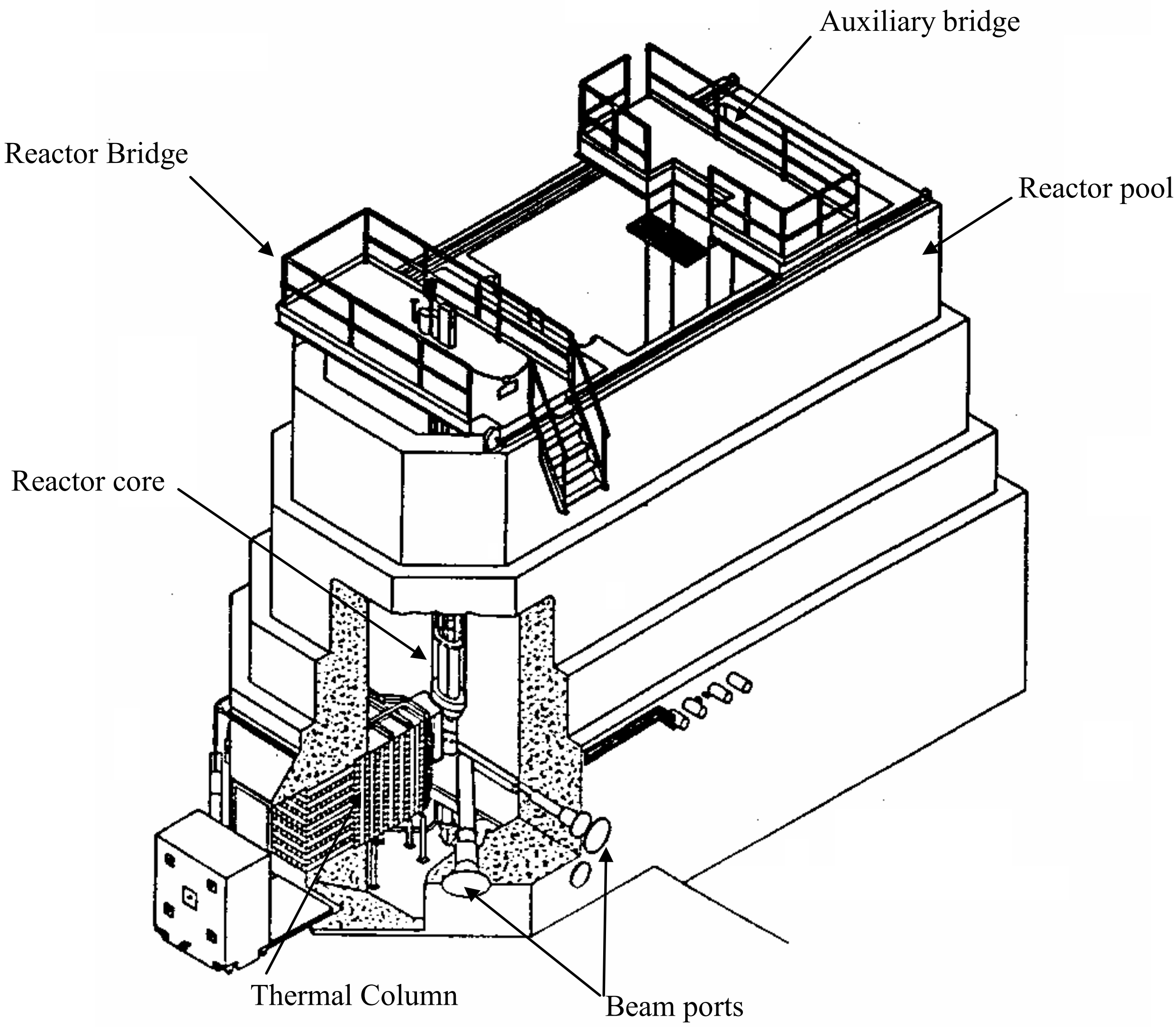


Fig. 1. Perspective view of TRR-1/M1 structures.

By2010, TRR-1/M1 had gone through 18 core configurations. The current core configuration uses two types of 20% enriched UZrH fuel elements, namely 8.5% wt. and 20% wt. uranium. Both fuel element types are identical in size and have the same cladding material (SS304).The 8.5% wt fuel element contains approximately 38 g of uranium while the 20% wt. fuel element contains approximately 98 g of uranium. The fuel elements are positioned in a grid plate forming hexagonal configuration. Five control rods are used in the reactor core, a safety rod, a regulating rod, two shim rods and a transient rod. The regulating, shim and safety rods are fuel follower control rods containing B_4C as the neutron absorber in the upper part of the rod while the lower part contains 20% wt. fuel. These fuel follower control rods are sealed in 304 stainless steel tubes. On the other hand, the transient rod is an air follower control rod containing B_4C as the neutron absorber in the upper part of the rod while the lower part is simply air filled. The air follower control rod has aluminum cladding. In the current core configuration, there are 107 fuel elements in total. There are a number of neutron irradiation facilities, including 10 in-core tubes (CT, C8, C12, F3, F12, F22, F29, G5, G22 and G33), and 12 out-core tubes and facilities (A1, A4, CA2, CA3, TA, TC, wet tube, SNIF, Rotary specimen rack, void tank and beam tubes and thermal column).The maximum neutron flux of TRR-1/M1 (at CT-Central Thimble position) is in the magnitude of 3×10^{13} $cm^{-2}s^{-1}$ at the nominal power of 1.2 MW. Figure 2 presents the current core configuration describing the locations of fuel elements, control rods and also the in-core irradiation facilities. Figure 3 also presents the diagram of the TRR-1/M1 out core irradiation facilities. The neutron flux at each irradiation facility is presented in Table 1.

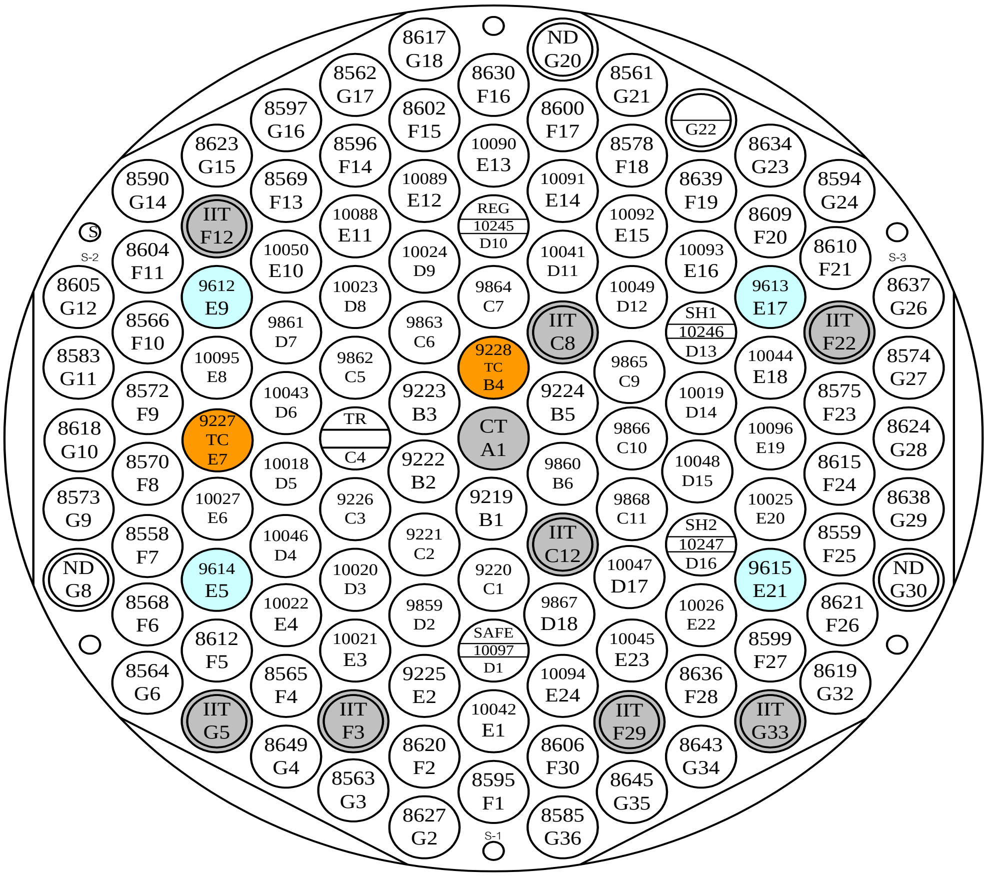


Fig. 2. Current TRR-1/M1 core configuration (core loading no. 18).

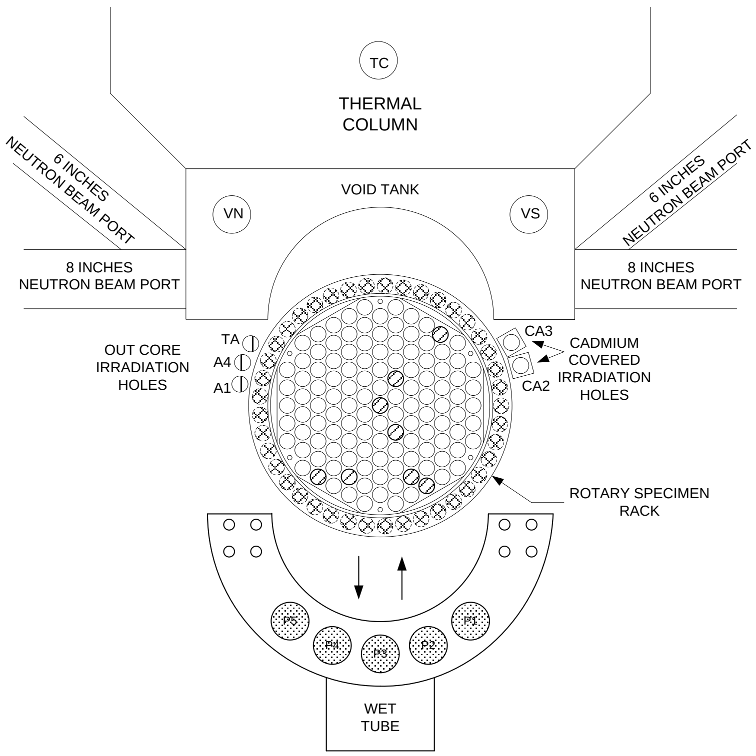


Fig. 3. Location diagram of the TRR-1/M1 out-core irradiation facilities.

TABLE 1. NEUTRON FLUX OF THE IRRADIATION FACILITIES IN THE TRR-1/M1 AT 1.2 MW.

No.	Detail	Neutron flux ($cm^{-2}s^{-1}$)			Cd Ratio (Au)	Thermal per Fast
		Thermal	Epithermal	Fast		
	In Core Facilities					
1	CT-1-3/4" wet tube	2.89E+13	2.27E+12	1.63E+13	2.65	1.77
2	C8-1-3/4" wet tube	2.01E+13	2.14E+12	1.38E+13	2.38	1.46
3	C12-1-3/4" wet tube	2.15E+13	2.60E+12	1.53E+13	2.35	1.41
4	F3-1-3/4" wet tube	1.20E+13	7.90E+11	7.31E+12	3.57	1.64
5	F12-1-3/4" wet tube	1.05E+13	9.13E+11	6.86E+12	3.05	1.53
6	F22-1-3/4 " wet tube	1.07E+13	7.60E+11	6.16E+12	3.21	1.74
7	F29-1-3/4" wet tube	1.25E+13	8.16E+11	5.04E+12	3.08	2.48
8	G5-1-3/4" wet tube	9.07E+12	6.21E+11	4.44E+12	3.77	2.04
9	G33-1-3/4" wet tube	9.28E+12	3.95E+11	3.64E+12	4.16	2.55
10	G22-1-3/4" dry tube	5.81E+12	5.01E+11	3.35E+12	2.87	1.73
	Out core facilities					
11	A1-1-3/8" dry tube	2.06E+11	2.35E+10	8.95E+10	2.28	2.31
12	CA2-1-3/8" dry tube	1.62E+11	2.73E+09	7.18E+10	10.83	2.26
13	CA3-1-3/4" dry tube	1.49E+11	1.81E+09	5.50E+10	12.68	2.71
14	A4-1-1/2" dry tube	5.15E+10	1.83E+09	4.45E+10	5.53	1.16
15	TA-1-3/4" dry tube	4.47E+10	3.57E+09	2.56E+10	2.96	1.75
16	Lazy Susan 41 dry tubes	2.55E+11	7.88E+09	4.80E+10	7.49	5.31
17	SNIF dry tube	1E+6		1E+6		

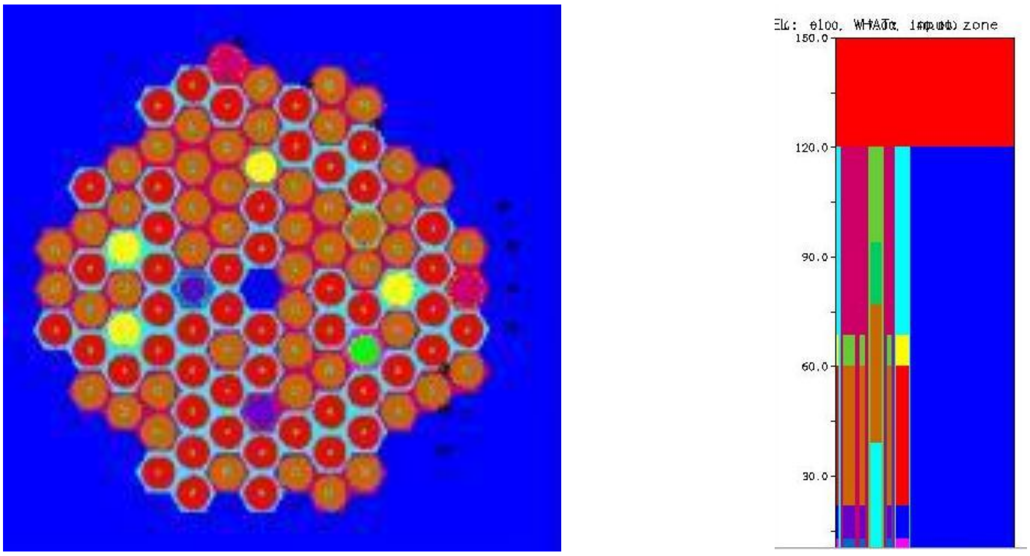
18	Thermal Column	1E+9				
19	Beams-6" and 8"dry tubes			1E+6		
20	WT-13 wet tubes	8.09E+11	3.10E+10	3.32E+11	5.55	2.44

3. TRR-1/M1 OPERATION, MAINTENANCE AND FUEL MANAGEMENT PROGRAM

The philosophy of the operation, maintenance and fuel management programme of the TRR-1/M1 is to endeavor its best performance and hence enhance the utilization of the TRR-1/M1. Assurance of stable reactor operation, high reliability and ultimate safety are provided for all reactor users.

The operation, maintenance and fuel management of TRR-1/M1 is under the responsibility of the reactor management section of the Division of Nuclear Technology Operation. There are currently 18 staff members in this section. Routine operation is scheduled on Tuesday to Thursday between 8:30 and20:30 and on Friday between 8:30 and 18:30, while Monday is reserved for weekly inspection and minor maintenance as well as special experiments and training. A major maintenance shutdown is annually scheduled for 45days during February and March each year. In conclusion, the reactor is nominally operated at the power of 1.2MW for 10.5 months to reach the burn up target of 90 MWd.

Fuel reloading is mostly performed biennially. The fuel management utilizes advanced 3D neutronics calculations to determine the core loading pattern. These 3D neutronics calculations are performed by such computer codes as SRAC [2] and MVP [3]. The computational methodology implemented in SRAC is similar to the typical fuel management methodology adopted by commercial nuclear power reactors. This methodology is to generate the few-group cross sections by detailed transport calculation and subsequently performs the whole core calculation by a diffusion calculation with the generated few-group cross section. On the contrary, MVP is a Monte Carlo method code which simulates a whole core with less approximation as compared to SRAC. Both SRAC and MVP codes are used in conjunction to evaluate a new core loading pattern. The reactor core model of TRR-1/M1 by 3D Monte Carlo MVP computer code is shown in Figure 4 as the example.



Top view *Axial View*

Fig. 4. MVP model of TRR-1/M1.

Each hexagon in Figure 4 represents a fuel lattice comprising of a fuel element and surrounding water. Safety analysis is performed to ensure the safety of the reactor management programme. A steady-state thermal hydraulics COOLODN2 computer code [4] has been adopted to assess the thermal safety margin for TRR-1/M1. The code has also been validated against the experimental data and measurement. Mostly, the model slightly overestimates the measurements. Thus, its results are applicable for steady-state safety assessment of the TRR-1/M1. Reactivity insertion analysis is also performed by using the EUREKA-2/RR computer code [5] to verify that, even in case of transient accident, the reactor is still under safety limits.

4. CURRENT UTILIZATION OF TRR-1/M1

The TRR-1/M1 is currently the largest neutron source in Thailand. The reactor attracts quite a number of reactor users for different purposes. The applications of TRR-1/M1 can be broadly categorized as irradiation services (e.g., isotope productions, analytical services and gems colorization), experimental research, education and training, and public relations [7]. The list of utilizations of the irradiation facility at the TRR-1/M1 in 2009 is summarized in Table 2.

TABLE 2. UTILIZATION OF THE TRR-1/M1 IRRADIATION FACILITIES IN 2009.

In core Facility	Main proposes	Targets	Products	Samples
CT	Isotope production	TeO_2, Sm_2O_3	I^{131}, Sm^{153}	17
C8, C12, F29	Isotope production	TeO_2	I^{131}	9
F3	Isotope production	Lu_2O_3, TeO_2	Lu^{177}, I^{131}	8
G5, G33	Isotope production	NH_4HPO_4, TeO_2	P^{32}, I^{131}	65
F12, F22	Experiments	Gems	Colourization	13
G22	R&D	Foods, ores, particulate	Short live isotopes	560
Out core facility	Main proposes	Targets	Products	No.
A1, CA2, TA	R&D	Food, environmental	Medium live isotopes	246
A4, CA3	Services	Alloy, Ore, sludge	Medium live isotopes	61
LZ	R&D	Food, environmental	Long love isotopes	77
WT	Services	Gems	Colourization	55
Column & Beams	Experiments	Antiques	Radiography	11
SNIFFS	Experiments	Seeds	Mutation	17

More explanation is described in the following sections.

4.1. Isotope production

Isotope production is one of the main uses for the TRR-1/M1. The target for isotope production is irradiated at the relatively high neutron flux regions of the reactor core, that is, the in-core irradiation facilities. The in-core irradiation facilities, CT, C8, C12, F3, F29, G5 and G33 are normally reserved for isotope production. Typical irradiation time per batch is approximately eight weeks. After irradiation, the irradiated target is processed in a hot cell in the isotope center close to the reactor building. The total capacity with all the in-core irradiation facilities is approximately 4.5 Ci/week. This production capacity suffices roughly half of the domestic demand.

The special service Isotope Production Center of TINT is dedicated to radioisotope production and sale. The main radioisotope produced by TRR-1/M1 is I-131 from TeO_2 targets in solution and many labeled forms, mostly for medical applications. The production of other isotopes, though on occasional basis, includes Sm-153 for medical applications and P-32 for agricultural applications. Table 3 summarizes radioisotope products, income and the number of medical diagnostic and treatment cases in 2009.

TABLE 3. RADIOISOTOPE PRODUCTS, INCOME AND MEDICAL APPLICATION CASES IN 2009.

Number	Product	Unit	total	Income (Baht)	Cases
1	I^{131}-solution	mCi	173,963	5,218,890	1,150
2	I^{131}-Diagnostic Capsule	mCi	93	9,300	93
3	I^{131}-Therapeutic Capsule(1-10mCi)	Capsules	1,218	1,365,840	1,175
4	I^{131}-Therapeutic Capsule(11-20mCi)	Capsules	214	352,800	209
5	I^{131}-Therapeutic Capsule(21-50mCi)	Capsules	5,359	15,460,000	1,954
6	I^{131}-MIBG Diagnostic Dose	mCi	133	465,500	138
7	I^{131}-MIBG Therapeutic Dose	mCi	560	196,000	4
8	I^{131}-Hippuran	mCi	144	100,800	144
9	Sm^{153}-EDTMP	mCi	2,255	225,500	34
10	P^{32}	mCi	18	1,800	
	Total Income and cases			23,396,430	4,901
	(Income from RR products)			(11,698,215)	

4.2. Gemstone irradiation

The Gemstone Irradiation Center of TINT is responsible for gemstone irradiation operation. Topaz is the most common gemstone being irradiation at TRR-1/M1. Neutron irradiation transforms the naturally occurring colorless Topaz into blue Topaz which enhances its values up to 30 times. Gemstone irradiation typically requires fast neutrons; therefore, it is usually irradiated in the relatively high fast flux region. The in-core irradiation facilities in the outer rings of the core are suitable for gemstone irradiation since they have a high fast flux. The in-core irradiation facilities, F12 and F22, are normally reserved for gemstone irradiation. It should be noted that, although the in-core irradiation facilities of the inner rings generally have a higher fast flux, they are probably more valuable for applications requiring a high thermal flux such as isotope production. Gemstones to be irradiated in the in-core facilities are restrained by their size due to limited space in the core. The TRR-1/M1 has also out-of-core irradiation facilities which are currently used for gemstone irradiation. Gemstones with larger size can be irradiated in these out-of-core irradiation facilities. Out-of-core irradiation facilities (e.g., VS, VN, wet tubes) are normally reserved for gemstone irradiation. The typical gemstone irradiation time per batch is 2 weeks for in-core positions and 3–6 months for out-of-core positions. The current gemstone irradiation capacity of the TRR-1/M1 is approximate 150 kg annually. The irradiation of gemstones in 2009 was 27 kg with an income of 951 276 Thai Baht (approximately 32 000 US$).

4.3. Neutron activation analysis (NAA)

The Nuclear Service Center renders services on NAA of ore from mining and elemental analysis in sludge, along with other techniques such as X ray fluorescence. However, the income from NAA service is still limited to 4 percent of the total analytical services income of 3 063 517 Baht in 2009. NAA is also a prominent technique of the Research and Development Group for trace elemental analysis of agricultural products, foods and air particulates, etc. The irradiation facilities most available for NAA are the in-core G22 pneumatic dry tube and other out-of-core dry tubes such as A1, CA2, CA3, A4, TA, TC and the rotary specimen rack with 41 irradiation positions.

4.4. Research and development

A few research and development projects based on neutron experiments conducted at the TRR-1/M1 include neutron radiography of antiques, neutron tomography, neutron scattering, prompt gamma NAA and plant mutation. Both in-core and out-of-core irradiation facilities are available upon request by users. There were two publications in 2010 [8] and [9].

4.5. Education and public relation technology transfer

A critical approach along with other reactor experiments conducted for university students is nuclear technology and engineering training. Reactor operator training and refreshment is scheduled biannually. A reactor visit is also part of the public relations programme. The average number of visitor is 2000 per annum.

5. FUTURE UTILIZATION PLAN

To support promotion and enhancement of TRR-1/M1 utilization, a working group has been assigned to identify needs, opportunities and problems, as well as to formulate the proper utilization plan for the next year. More collaboration with universities, laboratories, research institutes and end users will be encouraged. Neutron radiography and forensic sciences are the main topics of interest. The reactor would also be used as the educational platform for human development programs in nuclear engineering, nuclear and radiation safety, safe guards, etc., toward nuclear power development.

6. CONCLUSION

The Thai Research Reactor TRR-1/M1mainly supports research and development, education and public relations, and technology transfer, while partly providing commercial radioisotope products and analytical services to the public. The total income from reactor utilization was around 0.45 million US$ in 2009. TINT will try to promote and enhanceTRR-1/M1 utilization through collaboration with end users.

7. REFERENCES

[1] THAILAN INSTITUTE OF NUCLEAR TECHNOLOGY, TRR-1/M1 Safety Analysis Report, TINT, Bangkok (2003).

[2] OKUMURA, K., KUGO, T., KANEKO, K., TSUCHIHASHI, K., SRAC (Ver. 2002); The comprehensive neutronics calculation system, Japan Atomic Energy Research Institute, Tokai-mura (2002).

[3] JAPAN ATOMIC ENERGY RESEARCH INSTITUTE, MVP/GMVP II: General Purpose Monte Carlo Codes for Neutron and Photon TransportCalculations based on Continuous Energy and Multigroup Methods, S. Matsuda Ed., JAERI 1348, Japan Atomic Energy Research Institute, Tokai-mura (2005).

[4] KAMINAGA, M., COOLOD-N2: A computer code for the analyses of stead-state thermal-hydraulics in research reactors, (1994).
[5] KAMINAGA, M., EUREKA-2/RR: A computer code for the reactivity accident analyses in the research reactor, (1996).
[6] TIPPAYAKUL, C., SAENGCHANTR, D., "Fuel management methodology upgrade of Thai Research Reactor (TRR-1/M1) using SRAC computer code", 2nd International Conference on Research Reactors: Safe Management and Effective Utilization, Australia 2007, International Atomic Energy Agency, Vienna (2008).
[7] THAILAND INSTITUTE OF NUCLEAR TECHNOLOGY, TINT Annual Report 2009, TINT, Bangkok (2009) 44–48.
[8] SUKROD, K., SRISATIT, S., "Development of the profile Data Acquisition System for Neutron Computed Tomography for the Thai Research reactor TRR/M1", Siam Physics Congress 2010.
[9] FUNGKLIN, R., "Application of neutron radiography using neutron imaging plate for inspection of ancient objects", Master Thesis, Chulalongkorn University, Bangkok (2010).