UTILIZATION OF RESEARCH REACTORS - A GLOBAL PERSPECTIVE

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Introduction

This paper will present 1) a worldwide picture of research reactors, operable, shutdown, under construction and planned, 2) statistics on utilization of research reactors including TRIGA reactors, and 3) some results of a survey conducted during 1988 on the utilization of research reactors in developing Member States in the Asia-Pacific Region.

The statistics are derived from the Agency's computerized Research Reactor Data Base (RRDB). The information was collected by the Agency through questionnaires sent to research reactor operators in 1985 and 1986. All data on research reactors, training reactors, test reactors, prototype reactors and critical assemblies are stored in the RRDB. This system contains all the information and data previously published in the Agency's publication, Power and Research Reactors in Member States, as well as updated information.

Reactor operators were asked to confirm only the general information for reactors shutdown, and to update the information on operational reactors and reactors under construction. Nearly all reactor operators returned the questionnaire; however, a few (13) reactor operators did not respond. The reactors for which no updated information was received or for which information is not readily available in the open literature are classified as unverified information but for statistical purposes, these reactors were assumed to be operational. Reactors that have been shut down temporarily for modifications or upgrading were also considered as operational.

Global Characterization of Research Reactors

According to the information available to the Agency at the end of June 1988, there were 325 nuclear research reactors operating in the world. To date, 205 have been shut down, 17 are currently under construction, and 18 new facilities are planned. While developing countries account for less than one-quarter of the operating facilities, they account for most of the facilities under construction or planned.

Operating Reactors

The 325 operating reactors are located in 56 countries. Their geographical/political distribution is as follows:

North America	116
Europe (Western)	94
Asia - Pacific	52
South America	13
Africa	4
Middle East	5
Europe (Eastern)	17
USSR	24
	325

(VG-2)

Countries with the largest number of research reactors are:

USA	99
USSR	24
FRG	21
France	20
Japan	18
UK	15
Canada	14
	211 (65%)

It should be noted that 45 of the reactors in the USA are Department of Energy reactors. The reactors in the RRDB range in power from 0 to 250 MW. About 25% of the reactors are rated at less than 1 KW including 46 that are classified as zero power. Forty two percent of the reactors are rated at less than 100 kW. As will be shown later, this class of reactors have the lowest utilization of the group.

(VG-3)

The age of operating reactors is surprisingly high. Most reactors are over 20 years old. Their ages range from newly commissioned to 42 years old. The average age is 22.4 years with the median age of 24 years. While many reactors have undergone continuous renewal, this aspect of age may have a large impact on future renewals and shutdowns.

(VG-4)

Constructions

The research reactors commissioned since 1980 are listed below. It should be noted that 14 of the 20 listed are in developing countries.

France	ORPHEE	14,000 kW	1980
USA	FFTF	40,000 kW	1980
Canada	SLOWPOKE	20 kW	1981
USSR	ARGUS	50 kW	1981
Argentina	RA-6	500 kW	1982
Czechoslovakia	LR-0	5 kW	1982
France	SCARABEE N	100,000 kW	1982
Korea, R. of	AGN-201	0 kW	1982
Malaysia	TRIGA-PUSPATI	1,000 kW	1982
Libya	IRT-1	10,000 kW	1983
Canada	SLOWPOKE	20 kW	1984
China	MNSR	27 kW	1984
India	PURNIMA-II	5 kW	1984
Jamaica	SLOWPOKE	20 kW	1984
India	DRHUVA	100,000 kW	1985
India	FBTR	40,000 kW	1985
Bangladesh	TRIGA MK II	3,000 kW	1986
Canada	SDR	2,000 kW	1987
Indonesia	RSG-GAS-30	30,000 kW	1987
Iraq	TAMMUZ-2	500 kW	1987

Research reactors under construction include the following, with expected criticality dates indicated when known:

Canada	MAPLE X-10	10,000 kW	1991
Chile	LO AGUIRE	10,000 kW	1988
China	PPR-PULSING	1,000 kW	1988
	LTHR	5,000 kW	1988
	LPR	5,000 kW	1989
Czechoslovakia	VR-1P	10 kW	1988
	VR-1B	100 kW	1990
Algeria	---	500 kW	?
India	KAMINI	100 kW	?
Iran	ZPR	0 kW	?
Japan	Upgraded JRR-3	20,000 kW	1989
Korea, R. of	KMRR	30,000 kW	1990
Morocco	MA-R1	1,000 kW	1990
Peru	PER-2	10,000 kW	1988
USSR	PIX	100,000 kW	?
USA	SNRS	1,000 kW	1989
	TRIGA-II-TEXAS	1,000 kW	1988

Developing countries account for 12 of the 17 construction projects.

Planned/Under Consideration

The following countries have indicated interest in a new reactor and are in various stages of study, planning or negotiations. How realistic the expectations are cannot be assessed at this time.

Argentina	Sri Lanka
Colombia	Madagascar
Cuba	Nigeria
Ecuador	Poland
Egypt	Saudi Arabia
Ghana	Syria
Japan	USA
Korea, DPR	Uruguay

Shutdown Reactors

The RRDB shows 205 research reactors shutdown. Nearly all of these have been in industrialized countries where the reactor was shutdown because the specific mission of the reactor had been fulfilled or for financial and low utilization considerations. A few, however, may have been shut down for concerns of aging, and replaced with newer designs or for problems of safety backfitting.

Utilization - Worldwide

In order to categorize research reactor utilization based on information received from reactor operators, the following criteria has been used. It should be noted that this categorization is based only on annual hours of operation and does not consider extent of use of installed facilities or the quality of utilization.

A.	Maximum Utilization	$\geq$ 6000 hr/yr
B.	High Utilization	2000 - 6000 hr/yr i.e. 1 - 2 shifts/day
C.	Good Utilization	1200 - 2000 hr/yr i.e. $\sim$ 1 shift/day
D.	Low Utilization	800 - 1200 hr/yr i.e. 1/2 - 3/4 shifts/day
E.	Under Utilization	$<$800 hr/yr

A total of 216 reactor operators provided varying degrees of detail on utilization. This group includes 40 TRIGA reactor operators. The breakdown of the reactors are as follows:

Maximum Utilization -
58 reactors (14.8%) including 2 TRIGAs
Average Power of reactor = 25.1 MW

High Utilization -
58 reactors (26.9%) including 10 TRIGAS
Average Power of reactors = 13.5 MW

Good Utilization -
39 reactors (18.1%) including 11 TRIGAS
Average Power of reactors = 4.5 MW

Low Utilization -
25 reactors (11.6%) including 6 TRIGAS
Average Power of reactors = 0.34 MW

Under Utilization -
62 reactors (28.7%) including 11 TRIGAS
Average Power of reactors = 0.15 MW

Comparing TRIGA reactors with the rest of the reactor population, we find that, based on daily operating hours reported, 78 % of TRIGA reactors operate one-shift or more compared to 60% of the rest of the reactors. At the lower end, 12.5% of TRIGAs are underutilized against 29% for the rest.

There appears to be a direct correlation between reactor power and use. Most highly used reactors are involved in materials testing, radioisotope production on a large scale, or neutron beam work. In the lowest category, most of the reactors are very low power or critical assemblies designed for specific studies or high power reactor mock-ups. As far as the TRIGA reactor statistics in this lowest category, most of the reactors are located in American universities and are used almost exclusively for education and training courses, hence only on an as needed basis.

A question often asked is the importance or role of a research reactor in a nuclear power program. Without drawing any conclusions, the statistics show that of the 26 Member States with nuclear power programs all operate research reactors. In fact, this group operates 271 research reactors. Six countries with nuclear power plants under construction operate 17 research reactors. Only one country, Cuba, has no research reactor but is negotiating the purchase of two.

Asia-Pacific Developing Countries

The research reactors in developing member states in the Asia-Pacific region were studied in greater detail through special questionnaires sent to reactor operators. Twenty four questionnaires were sent out and 16 replies were received. Of the 16 replies received, five were not included in the statistics because two were too new to have established utilization programs and three others because of use restricted to education and training. The Indian research reactors are not included in this summary because their data were received too late. However, India could hardly be considered a scientifically or technically developing country. Their reactors, mostly of indigenous design and construction are well utilized and heavily into basic and applied research. The inclusion of their data would have presented an overly optimistic picture of utilization in the region. The reactors in the statistical base may be characterized as follows:

Age	15.1 yrs	median 16-11 yrs.	
Power	14.1 MW : without HFETR = 3.0		med = 2.8 - 2.0
Hours of operation	2524 hrs/yr		

Neutron Activation Analysis (NAA)

NAA is the most popular use of reactor neutrons in the region. Eleven reactors have NAA programs of varying levels. The average number of samples analyzed in a year is 3840 with the numbers ranging from 200 to over 12,000. The largest number of samples are for geological exploration. The results of the survey are as follows:

Field	No. of reactors doing NAA in Field	No. of reactors with greatest no. in Field
Geological	ALL	6
Environmental	10	0
Medical/health, etc.	9	2
Agriculture	7	2
Industrial	8	0
Universities	8	0
In-House Research	7	1
Others	6	0

Radioisotope Production

Ten reactors produce radioisotopes totalling 164,500 to 273,700 curies including large quantities of Co-60. If Co-60 is excuded, the totals are 900 Ci (1985) to 1250 Ci (1987). The results of the survey are summarized below.

Medical (7 reactors)
1987 - 86,190 Ci including 84,000 Ci of Co-60
Radioisotopes include: Mo-99, I-131, Au-198, P-32, Cr-51, Co-60

Agriculture (7 reactors) - produced tracer level quantities of: P-32, Ca-45, C-14, Rb-86

Industrial (6 reactors)
Co-60, Ir-192, Cr-51, Zn-65, I-131, Br-82, La-140, Ba-131, Po-210, Au-198, Na-24, Be-7

Universities (4 reactors)
Am-241, Cs-134, Co-60, C-14, P-32, Pt-197, Br-82, S-32, K-42, Ca-45, Ag-110m, Na-24, Mo-99, Rb-86, Cr-51, Fe-59, Au-198

In-House Use (4 reactors)
Mo-99, Co-60, Br-82, Ag-110m, Sb-122, Ba-131, P-32, Fe-59, Cr-51, Cu-64, Au-198, K-42, Na-24, Rb-86, Zn-65

Other Uses (4 reactors)
Sn-113, P-32, S-35, Ca-45, Cr-51, Br-82, Na-24, Z-65, Cu-64

Basic Research Projects as Reported

CN-2	Thermal Neutron Cross-Section Fission Yields Ternary Fission and Cold Fragmentation
CN-5	Low Energy Neutron Physics Reactor Materials
CN-9	Neutron Physics, Nuclear Physics, Radiochemistry, Radiation Damage, Neutron Spectroscopy, Reactor Engineering, Materials
ID-1	Crystal Structure, Magnetic Structure Texture
KR-2	Texture
PK-1	Debye-Waller Factors, Phonon Dispersion in Mixed Alkali-halides, Phase Transitions, Polymers
VN-1	Low Energy Neutron Physics Reactor Materials

In the area of neutron scattering, the region has 12 spectrometers installed at 5 reactors, 3 are under construction or in the design phase and 9 additional are planned. If all are constructed, spectrometers will be installed at 8 reactors.

Neutron Radiography

There are 6 neutron radiography facilities installed and an additional 4 are planned. The operating facilities average 136 radiographs per year ranging from 57 to 250 annually.

Education and Training

Fourteen reactors reported activities in this area of utilization. Although most involve reactor operator and other reactor related training, a very large range of fields have been specified. The average for the reactors is 300 students although a more typical number is about 40. One reactor reported 3743 students per year. TRIGA reactors (6) average 624 students including the 3743 students mentioned above.

Other Uses

A large number of varied activities had been reported in this category. In addition to the expected NTD silicon and materials testing, the other activities are listed below by reactors.

CN-2	NTD Silicon Fuel and Materials Testing
CN-5	NTD Silicon Fuel and Materials Testing
CN-9	Nucleopore Membrane Standard Neutron Field Neutron Filter NTD Silicon Radiation Processing Gemstone Coloring
CN-11	Shielding Biological Effects of Radiation NTD Silicon Fast Neutron Irradiation of Semi-conductors Nucleopore Membrane Use of Nuclear Heat
ID-1	Reactor Kinetics Reactor Parameter Measurements Temperature and Flux Distribution Gamma Dose Rate Heating
MY-1	Reactor Interfacing System Development Noise Analysis Thermal-hydraulic Research Fuel Management Code Development
TH-1	Gemstone Irradiation Reactor Experiments
VN-1	Use of Ge-71 as XRF Source Flux Trap as Gamma Irradiator for Polymerization

Summary

1. New Research Reactor projects are increasing in developing countries with many cases of first reactors being installed or planned. In industrialized countries, new reactors planned are generally high performance machines for specific purposes.

2. Utilization statistics indicate good usage of research

reactors. The figures should improve if only general purpose reactors were considered and not include the zero power specific purpose devices. These reactors, 46 in number, have the lowest utilization.

3. Utilization in developing countries show good increases based on the data received from the Asia-Pacific region. The greatest use of research reactors in this region is in NAA and radioisotope production; NAA mostly for geological exploration and to a lesser extent for medical/biological applications and in agriculture. Radioisotope production is mainly for medicine, agriculture and industrial applications.

4. Utilization in basic research is emerging. In the Asia-Pacific area, newly commissioned/recommissioned reactors in the Philippines, Bangladesh and Indonesia will improve the utilization in that area. The Agency has Technical Cooperation projects in neutron spectrometry (basic and applied research) in Thailand, Malaysia, Bangladesh, and Indonesia.

5. It takes a minimum of about 5 years for a first research reactor in a developing country to establish a good reactor utilization program. The factors that influence this are many, mainly involving development of the necessary infrastructure within the reactor center and external to it. The time required to accomplish this should be recognized by those involved in programs to establish and improve utilization of research reactors.

6. Research reactors can be and are being used to the national benefit by providing services to governmental, health, agricultural, industrial and educational sectors.

RESEARCH REACTOR UTILIZATION
Questionnaire Respondents
Asia-Pacific Region Developing Countries

Country	Facility	Power (kW)	Criticality	Comments
Bangladesh				
	TRIGA MK II	3000	1986	newly commissioned
China				
	HWRR-II	15000	1958	
	HFETR	125000	1979	
	SPR	3500	1964	
	SPRR-300	3000	1979	
	TSINGHUA	2800	1964	
Indonesia				
	TRIGA BANDUNG	1000	1964	training only
	PPBMI-BATAN	100	1979	
	RSG-GAS	30000	1987	newly commissioned
Korea, Rep. of				
	TRIGA MK II	250	1962	mostly training
	TRIGA MK III	2000	1972	
	AGN 201	0	1982	educational only
Malaysia				
	TRIGA PUSPATI	1000	1982	
Pakistan				
	PARR	5000	1965	
Thailand				
	TRR-1/M1	2000	1962	
Viet Nam				
	DALAT RR	500	1963	reconstructed 1983