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USES OF A SMALL RESEARCH REACTOR IN BRAZIL

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ABSTRACT

Three research reactors have been in operation in Brazil. A TRIGA Mark I reactor, the IPR-R1, is located at the Nuclear Technology Development Center (CDTN) of the National Nuclear Energy Commission (CNEN), in Belo Horizonte. This reactor has been safely operating since 1960, totaling around 19,300 hours, at rated power levels up to 100 kW, delivering nearly 1,460 MWh and allowing irradiation of about 390,000 samples.

Over the years, the reactor has been used to set up staff expertise on reactor operation in order to provide and improve suitable means to exploit its capabilities. Also, the reactor has been effectively used for applied physics and chemistry research, radioisotope production, chemical analysis and training of personnel.

This paper briefly outlines the main historical facts and dates related to the IPR-R1 research reactor facilities, operating status, improvements on original reactor systems, uses in various scientific areas and some feasible prospects for future work.

MAIN HISTORICAL FACTS AND DATES

The start up of nuclear activities in Brazil occurred in the early 'fifties, as in many developed countries throughout the world, within the framework of university programmes. At that time three nuclear research institutes were founded in: Belo Horizonte (IPR in 1952), São Paulo (IEA in 1956) and Rio de Janeiro (IEN in 1962). The National Nuclear Energy Commission (CNEN) was set up in 1956 to coordinate the Brazilian effort toward atomic mineral prospecting and processing, to promote uses of nuclear energy and to regulate and inspect radiation applications. A few years later those centers, located in the neighbourhood of university campuses, were selected to host research reactors, namely: the IPR-R1 reactor in 1960 (100 kW), the IEA-R1 reactor in 1957 (2 MW) and the Argonauta reactor in 1965 (zero power).

Over the years, the research centers and their reactors have played an important role in developing indigenous scientific and technical background to support peaceful uses of nuclear radiation and the nuclear power implementation challenge[1]. The organization of the Brazilian Nuclear Programme has been, to a certain extent, changing during the last years. With regard to nuclear research and development tasks, nuclear centers management and research reactors design and operation, most of these activities are today undertaken by CNEN.

This paper is primarily concerned with the IPR-R1 research reactor. The Institute for Radioactive Research (IPR) was created, in 1952, in the School of Engineering at the Federal University of Minas Gerais (UFMG), in Belo Horizonte[2]. From 1965 to 1972 it was jointly administrated by the UFMG and the CNEN. From 1972 until 1988 it became the headquarters of the Nuclear Technology Development Center (CDTN) of the Brazilian Nuclear Company (NUCLEBRAS)[3]. As of August 1988, it is operated on behalf of CNEN.

THE NUCLEAR TECHNOLOGY DEVELOPMENT CENTER (CDTN)

Over the last three decades a broad spectrum of nuclear and non-nuclear technical activities were conducted, related to the fields of ore prospecting, petrography, mineral processing, chemical processes, uranium enrichement, materials testing, fuel element development, waste management, fuel reprocessing, reactor physics, accident analysis, reactor commissioning, thermal-hydraulic testing, electro-mechanical systems design, environmental engineering, radiation protection, licensing, irradiation, radioisotopes application, chemical analysis, mechanical systems construction, electronics, instrumentation development, nuclear measurements, computing, data processing, documentation and education.

The facilities occupy around 25,000 square meters located on a tract of nearly 200,000 square meters, where about 500 employees are presently at work. As far as main irradiating apparatuses are concerned the facility houses two 14 MeV neutron generators (KAMAN and SAMES), a 200 Ci irradiator of Cobalt-60 (AECL), a natural uranium metal fueled light water moderated subcritical assembly (URANIE), a natural uranium dioxide fueled heavy water moderated subcritical assembly (CAPITU), this one of domestic design and construction, and, finally, a TRIGA Mark I reactor (IPR-R1). A strong and mutually profitable co-operation has been practised with national and foreign nuclear centers, universities, institutions, associations and industries.

THE IPR-R1 TRIGA MARK I REACTOR

About 60 TRIGA reactors are in operation throughout the world[4]. According to a recent statistic carried out by IAEA they represent nearly one fifth of the total research reactors in operation[5]. Furthermore, if one defines a peak steady flux of 10^{13} neutrons.$cm^{-2}s^{-1}$ as an upper threshold for small reactors, then about sixty per cent of operating reactors are small sized. The IPR-R1 reactor was the first TRIGA Mark I model supplied by General Atomics (USA) to be built abroad.

The IPR-R1 reactor achieved first criticality on November, 6, 1960 and has been safely operating with minor changes with the original core. The characteristic features of TRIGA reactors are well known, nevertheless some specific data are here presented[6]. The below-ground core presently consists of 58 fuel-moderator TRIGA typical zirconium hydride rods, containing 8.0 wt% of uranium enriched to 20%, aluminum cladded. The reactor nominal power is 100 kW. Five irradiation facilities, with given respective thermal neutron fluxes, at 100 kW rated power, are available: a central thimble (4.3×10^{12} $cm^{-2}s^{-1}$), a rotary specimen rack supporting 40 evenly spaced tubular specimen containers (6.6×10^{11} $cm^{-2}s^{-1}$), two pneumatic transfer systems with terminuses in the core (1.7×10^{12} $cm^{-2}s^{-1}$) and outside the core (1.8×10^{11} $cm^{-2}s^{-1}$) and a neutron radiography device placed above the core (2.0×10^{8} $cm^{-2}s^{-1}$).

Starting from the original design, a series of modifications and improvements have been continuously made on the reactor's systems through the design and or construction of the following: an aluminum liner tank facing the steel-concrete pool, control rod drive mechanisms, a water purification system, a heat removal system rated up to 250 kW which allowed, in a first step, upgrading the power from 30 to 100 kW, an automated pneumatic transfer system, a neutron radiography device, electronic control modules, backup instrumentation and data processing systems. The reactor relicensing was required, a few years ago, to comply with more strict and modern regulations.

Some statistical figures on reactor performance and uses are presented in the following Table showing yearly operating hours, delivered thermal energy and the amount of irradiated samples.

YEARS	TIME (h)	ENERGY (kWh)	SAMPLES
1960	31	1,084	0
1961	1,255	47,151	484
1962	2,324	81,362	639
1963	440	15,232	784
1964	230	8,160	623
1965	249	9,725	1,001
1966	250	11,209	1,302
1967	210	12,973	6,277
1968	316	13,879	4,035
1969	511	37,815	5,926
1970	383	30,659	4,011
1971	488	36,921	4,263
1972	716	60,266	6,980
1973	671	48,986	6,929
1974	816	70,630	11,405
1975	768	69,503	12,469
1976	1,041	95,160	19,868
1977	1,354	133,639	31,799
1978	1,540	136,499	49,801
1979	713	70,361	26,737
1980	939	89,906	31,432
1981	916	85,695	34,675
1982	1,082	101,897	57,255
1983	581	54,539	25,441
1984	592	51,999	19,698
1985	365	32,756	10,884
1986	332	31,615	11,014
1987	201	18,999	4,105
TOTAL	19,314	1,458,620	389,801

IPR-R1 REACTOR OPERATION AND USAGE FIGURES

IPR-R1 REACTOR UTILIZATION

Over the years the main uses of the reactor have been obviously linked to the goals of the institutions to which the R&D Center has been attached, changing from basic to specific ones. Formerly the uses were mostly directed to elementary physics and chemistry studies and radioisotope production. Later on, they were devoted to analytical chemistry in various fields. Despite the shifting aims, it has been permanently used to improve personnel skills in reactor physics and operation, enabling improvements of the instrumentation and operation procedures of the reactor. The acquired knowledge has been transferred to students and scientists in various teaching modules. The following outline is a brief survey on the main topics.

RESEARCH

Today almost all the established routine techniques of reactor utilization listed below, started as research.

Angular correlation, nuclear reactions, neutron cross sections, applications of Szillard-Chalmers reaction, radiolysis and other effects of radiation on minerals and alloys, thermoluminescence effects, dosimetry, crystalline structure were studies made in nuclear physics and chemistry.

Thermal, intermediate and fast neutron fluxes measurements were done at the irradiation positions by foil activation. More recently, the boring of holes in the upper grid plate of the reactor made possible the introduction of special activation detectors between fuel elements, and in this way, allowed the measurement of neutron flux distribution and neutron spectra inside the reactor core, otherwise not accessible. The complete mapping of thermal and fast fluxes have thus been achieved. Neutron spectrum, determined at the central thimble, has permited studies for the establishment of theoretical models.

Noise analysis techniques have been applied to measure reactor parameters like temperature coefficients and the mean transit time of the cooling water through the reactor core. A pile oscillator has been used for cross section determinations.

Competence in the area of fuel burnup determination by using the non-destructive gamma-spectrometric method is being acquired with the gamma-scanning of irradiated fuel elements. Testing of structural materials has been done in small scale. Special studies of materials were carried out with the use of neutron radiography and autoradiography. An example is the control of fabrication of borated stainless steel.

NEUTRON ACTIVATION ANALYSIS

Activation analysis is by far the most extensive use of the reactor. Over the years, one has developed the capability to perform routinely the following analyses by this method [7]: Na-24, Al-28, Cl-38, K-42, Sc-46, V-52, Mn-56, Fe-59, Co-60, Cu-64, Zn-69, As-76, Se-75, Br-82, Pd-109, Ag-108, Sn-125, Sb-122, I-128, Cs-134, Ba-139, La-140, Ce-141, Nd-147, Sm-153, Eu-152, Gd-159, Dy-165, Hf-181, Ta-182, W-187, Pt-199, Au-198, Hg-203, Pa-233, U-239. Examples of eventual analyses already performed are: F-20, Mg-27, Cr-51, Ni-63, Ga-70, Rb-86, Mo-99, Cd-115, In-116, Te-131, Pr-142, Re-188, Ir-192, Tl-202. Irradiation followed by counting of delayed neutrons instead of the induced gamma radiation is also widely used for analysis of uranium and thorium.

In recent years, work related to those phases of the fuel cycle, being implemented in the country, account for about 80% of total irradiations. Delayed neutron techniques applied to ore samples have been a powerful tool in the assessment of the Brazilian mineral resources, helping to rank the country as the fifth in uranium reserves[8]. The same technique is used during the testing of methods to be applied to uranium ore processing. Delayed neutron methods and activation followed by fission products measurement are applied to uranium enrichment de termination. Tests of methods and materials to be used in radioactive waste disposal and the effectiveness of this disposal are done using the same techniques.

ISOTOPE PRODUCTION

Although not the reactor of the highest neutron flux among the Brazilian research reactors, the IPR-R1 reactor has its place as a supplier of radioactive isotopes. Those most commonly produced are: Na-24, P-32, Cr-51, Fe-59, Co-60, Mn-56, Br-82, I-131, Hf-181, Ir-192 and Au-198. Some examples of their utilization follow.

The Center has a long experience in the application of radioactive tracers and so radioisotopes are routinely produced for such uses. The areas of application are: studies of the transport of sediments and of solid and liquid wastes in rivers, harbours and open sea; flow measurements in rivers, oil and ore pipelines, and in pumps and turbines of hydroelectrical power plants; pollution and erosion studies in rivers and harbours; determination of steam moisture carryover in steam generators. Sources for industrial applications are supplied for instance, for studies in tile fabrication, cement industries, metallurgical furnaces. The production capability of the reactor is below the demand of the medical area which requires high specific activities. Even so, some isotopes are supplied for the medical and biological areas.

TRAINING

Since its installation, the reactor has been fundamental in the training of a number of scientists and technicians in many fields of reactor applications. The Center also offers a number of courses and lectures, using the reactor, for other institutions. Besides helping colleges and high schools with lectures and informative material, regular courses for postgraduate students in Nuclear Engineering are carried out for the local university. Access to the reactor installations is normally included for the following courses: reactor physics, nuclear and reactor engineering, radiation protection, nuclear physics and chemistry, application of radioisotopes and nuclear measurement techniques. Since 1970 the reactor has provided material for around 30 Master Theses and another number of term papers.

At the beginning of the construction of the first Brazilian Nuclear Power Plant a special training course in reactor operation for NPP operators was developed and has been given to about 200 people, ranging from supervisors, operators and managing personnel of NPP, to the reactor simulator crew, to personnel from the licensing organization and to IPR-R1 reactor operators.

PROSPECTS FOR THE FUTURE

Based on the accumulated experience of operation and utilization a few projects are envisioned for the near future:

- a deeper inspection of reactor main systems and components, specially the reactor fuel elements,
- the modernization of the instrumentation and control console,
- an appraisal of the previous work on reactor power upgrading to 250 kW and, eventually, its accomphisment with available stainless steel cladded fresh fuel elements,
- the design and construction of a new automated irradiation facility for short half-lived radionuclides chemical analysis, and
- the broadening and promotion of research reactor uses.

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