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THE ROLE OF A RESEARCH NUCLEAR REACTOR WITHIN THE FRAMEWORK OF MINERAL PROSPECTION AND PROCESSING PROGRAMS

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ABSTRACT

The Empresas Nucleares Brasileiras S.A. - NUCLEBRÁS own the only TRIGA MARK I nuclear reactor in Brazil, which is in operation at the Centro de Desenvolvimento da Tecnologia Nuclear - CDTN, in Belo Horizonte. This reactor operates since 1960 and was formerly intended for training, research and isotope production. Nowadays, it is worthwhile to emphasize its further application, as an important tool devoted to the chemical analyses, based on neutron--gamma and neutron-fission nuclear reactions.

An amount of about 240000 mineral samples have been irradiated in the reactor, since the foundation of the NUCLEBRÁS, in 1974. The analytical determinations according to activation methods allowed for a better evaluation of the uranium ore resources and, consequently, contributed to the achievement of present Brazilian position in the world market.

1. INTRODUCTION

Three decades ago, a group of scientists led by MAGALHÃES GOMES [1] foresaw that the peaceful uses of the nuclear energy should be overcome. This insight called forth the foundation of the Instituto de Pesquisas Radioativas -- IPR, in 1952, and the offering of the Curso de Engenharia Nuclear, in 1957, within the Escola de Engenharia da Universidade de Minas Gerais, in Belo Horizonte. As a further step, a TRIGA MARK I nuclear reactor, the so-called IPR-R1, was ordered. This reactor went critical on November, 6, 1960 and operates, appropriately, eversince.

The original IPR was jointly supported by the Universidade Federal de Minas Gerais and Comissão Nacional de Energia Nuclear from 1965 to 1972, when it has been incorporated to the Companhia Brasileira de Tecnologia Nuclear.

At the end of 1974 the Empresas Nucleares Brasileiras S.A. - NUCLEBRÁS were established to allow for the implementation of the Brazilian Nuclear Power Programme, as presented by NOGUEIRA BATISTA [2]. Under the aegis of NUCLEBRÁS, the IPR, gradually, became its research and development center: the Centro de Desenvolvimento da

Tecnologia Nuclear - CDTN. The CDTN provides a suitable backup to the Projects under way in the NUCLEBRÁS, which are linked to the nuclear power plants and nuclear fuel cycle technology, concerned primarily with scientific and technical infrastructure needs. In such a context, the support to mineral prospection and processing programs may be considered as an example case.

To support the activities in the mineral technology field, the use of suitable means for analytical determinations , either for uranium or for other chemical elements, is mandatory. In this search, a large amount of samples has been analysed by the Departamento de Apoio Técnico in the CDTN [3]. Many of the experiments have been carried out using the TRIGA reactor, namely those related to neutron activation and delayed neutrons analytical methods, which played a significant role, particularly in the assessment of the Brazilian available uranium resources.

2. THE IPR-R1 TRIGA MARK I NUCLEAR REACTOR

There are about 60 TRIGA reactors, in operation, throught the world, among which a few in the southern hemisphere [4] . These reactors have been designed, with intrinsec safe operation features, to fulfill the needs of nuclear activated materials production, pure and applied research in the biology, physics and chemistry areas and scientific training.

A vertical cross section of the IPR-R1 TRIGA MARK I reactor, which incorporates improvements made in the original design [5], is presented in Figure1. The cylindrical core is shown at the bottom of the water shielding pool. The core lattice consists, basically of 58 fuel-moderator rods of an alloy of uranium enriched to 20% and zirconium hydride, surrounded by a graphite reflector, light water cooled and controlled with boron carbide bars. The arrangement allows for a maximum neutron flux of 4.4×10^{12} $n.cm^{-2}.s^{-1}$.

For the common uses of the IPR-R1 reactor, four main irradiation facilities are available: the central thimble, the rotary specimen rack and two pneumatic transfer systems, In the central thimble one can have the maximum allowable neutron flux, the rack can be rotated and supports 40 evenly spaced tubular specimen containers and the pneumatic transfer systems are used to automatically convey the samples to and from two different irradiation positions in and in the neighbourhood of the core.

3. THE USE OF THE REACTOR AS AN ANALYTICAL TOOL

The use of nuclear methods in chemical analyses is of great importance because they allow the fast simultaneous determination of many elements in a matrix, besides being accurate, precise, sensitive and, often, non-destructive.

These methods are physically based on nuclear reactions caused by the absorption of sub-atomic particles by the nucleii. Among these particles the thermal neutrons have been more commonly used, due to its high probability of interaction with nucleii of many different elements.

When using a thermal nuclear reactor as a neutron source, neutron-gamma and neutron-fission reactions may occur depending on the target nature. These reactions are the basis of the wellknown neutron activation and delayed neutron analytical methods, respectively.

3.1. The Neutron Activation Method

After the irradiation, the activated nucleii, containing a slight neutron excess, as compared to stable ones, a nuclear transmutation may occur. The daugther nucleii are frequently in a excited state, decaying throught a number of emissions. Measuring the properties of such emissions, as energy, intensity and/or half-life, one can identify the produced isotope and, consequently, the nature and concentration of the element in the irradiated substance.

From practical standpoint, the neutron activation method has been incorporated to the IPR-R1 reactor capabilities by ALVARENGA and GOMES [6] and has been improved, eversince, to arrive to the present situation shown in Table 1, where the commonest elements and usual detection limits in rocks and minerals are given.

When this method is employed, the reactor rotary specimen rack is mostly used, in order to provide simultaneous irradiation of many samples (including standard ones) under the same neutron flux. Afterwards, the samples are taken off and their gamma spectra detected using NaI(Tl), Ge or Ge(Li) cristals with associated electronic and data processing systems, are analysed, allowing to identify the presence of the elements in the matrix. This procedure may include, in some special cases, the radiochemistry classical methods use.

3.2. The Delayed Neutron Method

In the case that a substance containing uranium or thorium is irradiated with neutrons, they may undergo fission spliting into fission products, with the statistical occurance of delayed neutrons emission. These neutrons present the advantage of enabling the counting outside the the reactor core.

The delayed neutron method was firstly introduced in the IPR-R1 reactor services scope by TUPYNAMBÁ [7] and improved, as far as automation is concerned, latter on.

Presently, this method is used for uranium determination in samples which are conveyed in and from the neighbourhood of the reactor core, through one of the pneumatic transfer systems. After irradiation, including those of standard samples, neutrons are counted with a data processing system coupled to a BF_3 detector and the uranium content in the substance is printed out.

This technique has been, step by step, optimised and represents, today, a powerfull tool for uranium determinations in a fast, cheap, accurate, precise and sensitive way.

4. IRRADIATION RESULTS

The number of irradiated samples during the last seven years, since NUCLEBRÁS start, is presented in Table 2, in such a way that four main uses are pointed out, namely: mineral technology, nuclear research, training and industrial applications. The first group is to be emphasized. It has been splited into different categories depending on the analyses objective: mineral resources evaluation, material tests, environmental control and analytical methods development.

In Figure 2 the number of irradiated samples as well as the energy released in the reactor, since 1960, is plotted, as function of the time. As far as minerals are concerned the delayed neutron technique is used for uranium determination and the neutron activation analysis is mostly employed for uranium, thorium, gold, iron, titanium, tungsten, aluminum, copper, zinc, tin, arsenic and rare earth determinations.

5. CONCLUSIONS

The expansion of Brazilian uranium reserves during the last seven years has been supported by NUCLEBRÁS [8,9] prospection programs. The total reserve expansion, which comprises the measured and inferred values, according to IAEA criteria, is shown in Figure 3. In the same figure are also plotted the accumulated number of irradiated samples whose analytical determinations allowed for the uranium reserves evaluation and processes development.

One can see that both curves behave similarly so demonstrating the role of the IPR-R1 TRIGA research nuclear reactor in the special case of uranium mineral prospection and processing programs.

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ELEMENT	ISOTOPE	SENSITIVITY (µg/g)	
		INAA*	RSAA**
Na	Na-24m	10	-
Al	Al-28	5	-
Cl	Cl-38m	50	10
K	K-42	100	-
Sc	Sc-46	2	0,5
V	V-52	2	-
Mn	Mn-56	2	0,1
Fe	Fe-51	1000	10
Co	Co-60	5	1
Cu	Cu-64	-	2
Zn	Zn-69m	100	5
As	As-76	5	0,5
Se	Se-75	10	2
Br	Br-82	10	5
Pd	Pd-109m	10	2
Ag	Ag-108	10	1
Sb	Sb-122	10	1
Cs	Cs-134	10	0,5
Ba	Ba-139	100	5
La	La-140	1	0,5
Ce	Ce-141	10	2
Sm	Sm-153	1	0,5
Dy	Dy-165	1	0,1
Hf	Hf-181	5	0,5
Ta	Ta-182	1	0,1
W	W-187	5	1
Pt	Pt-199	2	1
Au	Au-198	0,5	0,05
Th	Pa-233	10	5
U	U-239	20	0,1

* normal ** radiochemical separation

NEUTRON ACTIVATION ANALYSIS

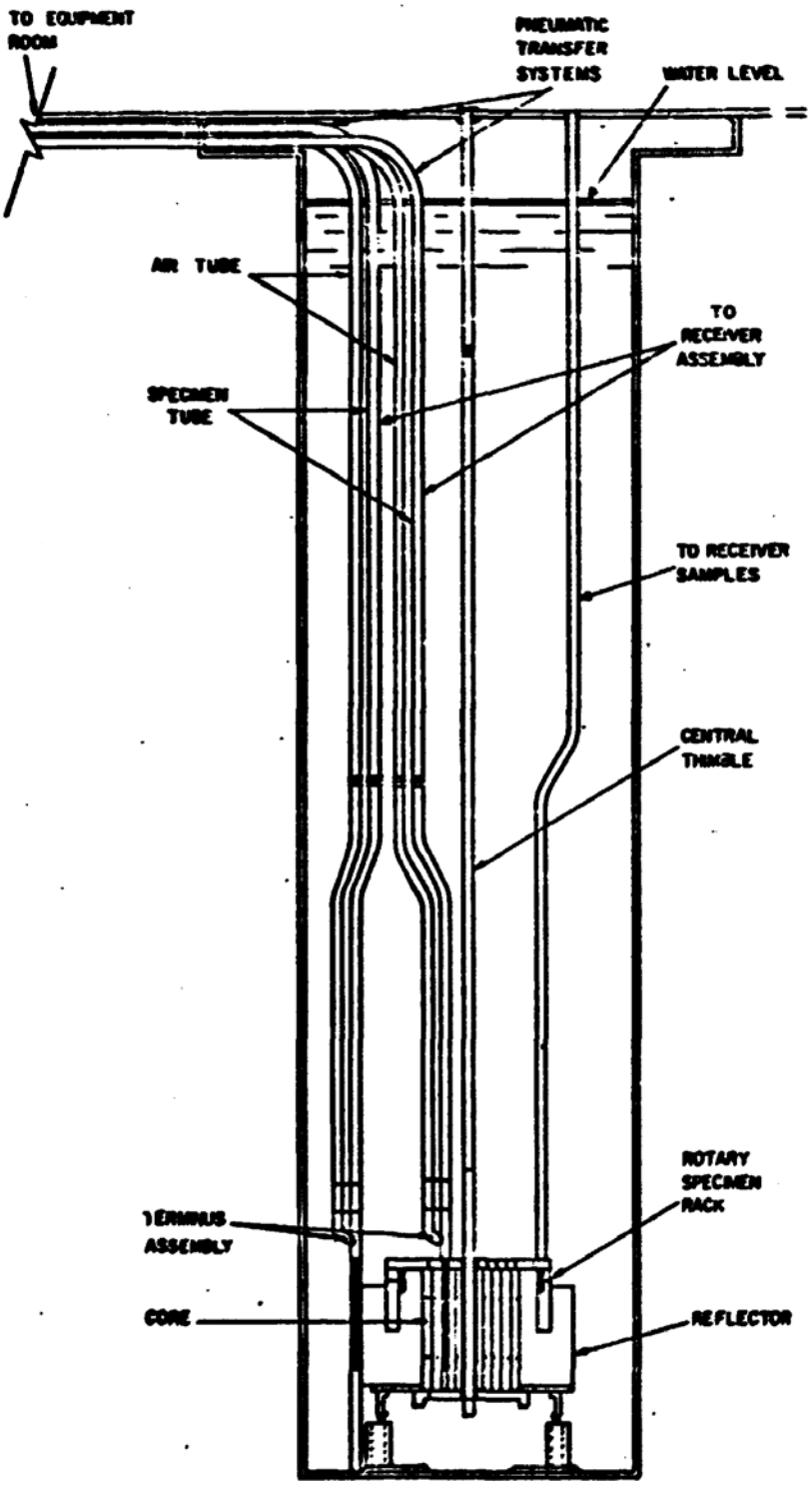
TABLE 1

YEAR	MINERAL TECHNOLOGY				NUCLEAR RESEARCH	TRAINING	INDUSTRIAL APPLICATIONS
	MINERALS	ENVIRONMENT CONTROL	MATERIALS	METHODS DEVELOPMENT			
1974	8835	70	96	1565	776	39	24
1975	10723	349	219	719	387	53	19
1976	18141	214	24	1045	338	67	39
1977	28767	1000	80	775	1113	08	56
1978	47794	995	05	628	260	55	64
1979	24168	997	16	1284	246	12	14
1980	28796	972	135	1332	165	15	17
1981	32897	311	100	1039	100	29	117
1982[a]	23870	362	130	1294	62	12	05
TOTAL	223991	5270	805	9681	3447	290	355

a - First semester

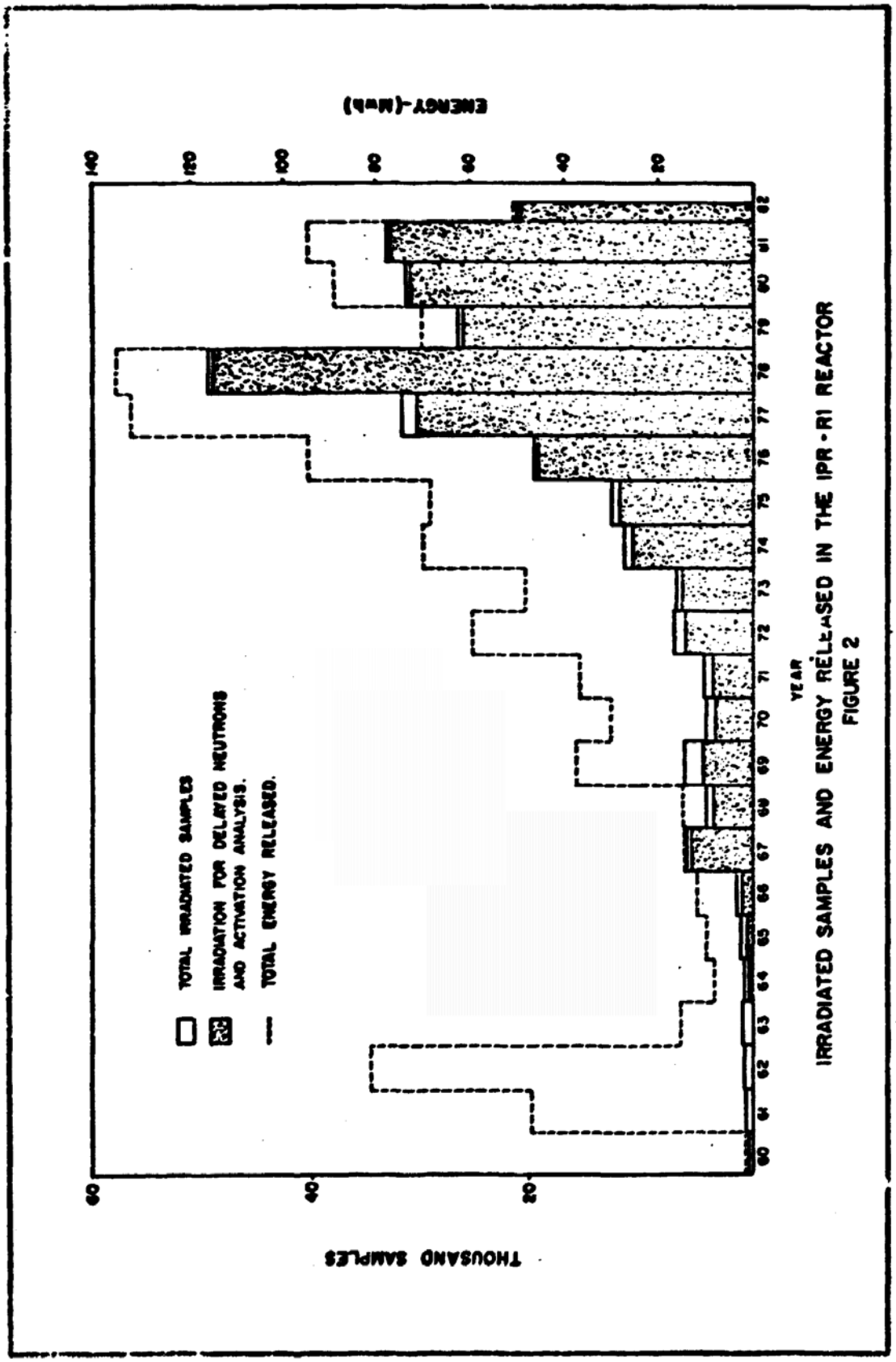
TOTAL IRRADIATED SAMPLES IN THE IPR-R1 REACTOR

TABLE 2

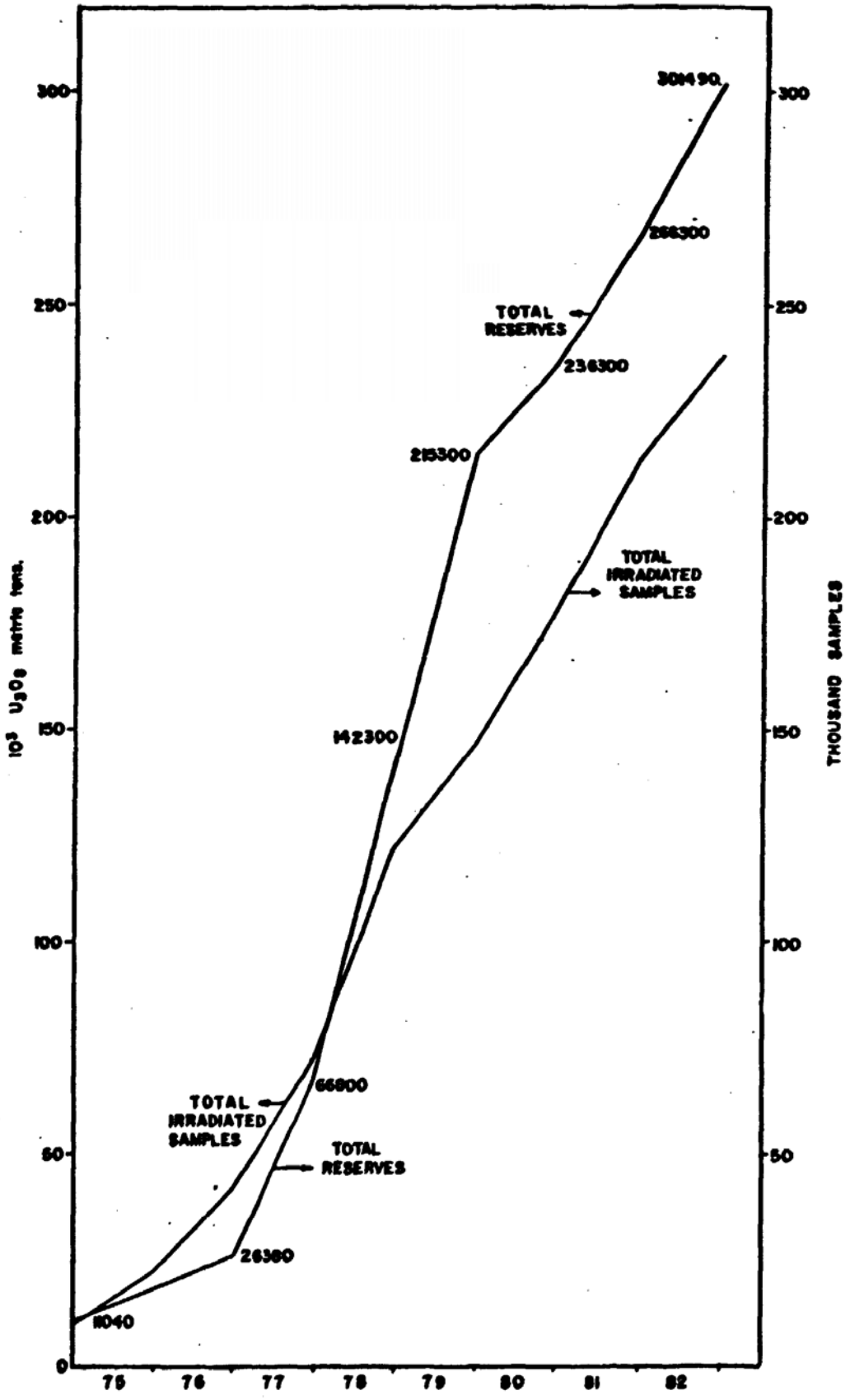


IPR-R1 TRIGA REACTOR TANK

FIGURE 1



IRRADIATED SAMPLES AND ENERGY RELEASED IN THE IPR-R1 REACTOR
FIGURE 2



EXPANSION OF BRAZILIAN URANIUM RESERVES

FIGURE 3