THE "RA" NUCLEAR RESEARCH REACTOR AT VINČA INSTITUTE AS AN ENGINEERING AND SCIENTIFIC CHALLENGE

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Abstract

The "RA" nuclear research reactor at the Vinča Institute of Nuclear Sciences is the largest nuclear research facility in Yugoslavia and belongs to that generation of research reactors which have had an important contribution to nuclear technology development. As these older reactors were generally not built to specific nuclear standards, new safety systems had to be installed at the "RA" reactor for a renewal of its operating licence in 1984 and it was shut down, after 25 years of operation. Although all the required and several additional systems were built for the restart of the "RA" reactor, a disruption of foreign delivery of new control equipment caused its conversion to a "dormant" facility, and it is still out of operation. In these circumstances, the re-start of the "RA" reactor became an open question, with other alternatives such as its conservation, or final shut-down and decommissioning taken also in consideration. Therefore, the future status of the "RA" reactor presents an engineering and scientific challenge to the engineers and scientists from Yugoslavia and other countries that may be interested to participate. To attract their attention on the subject, principal features of the "RA" reactor and its present status are described in detail, based on a recent engineering, economic and safety evaluation. A comparative review of the world research reactors is also presented.

1. INTRODUCTION

The nuclear research reactor "RA" at the Vinča Institute of Nuclear Sciences presents an important scientific and technological potential of Yugoslavia, as the country's largest nuclear research facility. The "RA" is a thermal heavy water moderated and cooled research reactor with a design output of 6.5/10.0 MW thermal. Original reactor fuel was a 2% enriched uranium metal with aluminium cladding in hollow cilinder form, but since 1976 a new fuel was used with 80% enriched uranium oxide dispersed in an aluminium matrix.

The "RA" reactor belongs to that generation of research reactors which have had an important contribution to nuclear technology development worldwide (some of these old generation reactors have already been shut down, but the majority is still in operation, either in their original design status or modified and refurbished). Constructed in 1959 according to the Soviet design and with Soviet equipment, the "RA" reactor has been successfully used for scientific research, but also for commercial purposes. Since an evaluation in 1981 has shown that the "RA" reactor was around half of its useful life, a decision was then made to redesign and to upgrade the reactor systems for a considerable improvement and modernization. It was also supplied by the fresh fuel for many years of future operation. However, in 1984 the "RA" reactor was shut down for the installation of additional safety systems as required for a renewal of its opearting licence according to the new licensing regulations imposed in the meantime.

In addition to the required emergency core cooling and emergency ventilation systems, new fuel handling mashine, new power supply system and a new water purification system for spent fuel storage pool were built in the meantime. To increase experimental capabilities, a new reactor loop was built for fuel testing and material irradiation experiments. New control and instrumentation was granted by the IAEA and contracted to be furnished by the end of 1990. However, after only a partial delivery, further deliveries have been suspended in 1991, but the old instrumentation and control has already been dismantled. Thus, the "RA" reactor is still out of service, kept as a "dormant" facility since 1984.

Obviously, the "RA" reactor with the new systems and fuel presents a considerable scientific and economic value and therefore an important national resource. As any other resource, it deserves an evaluation of either its use (if the need and possibility exist) or further preservation (if its latter use is probable), or abandonment (if not). However, its ageing and physical degradation mean that the value of this resource is being permanently lost, while, on the other hand, the risk of reduced safety increases, thus making this loss even faster. Also, corrosion of sensitive components (fuel element, reactor vessel) and some earlier operational failures (heavy water pumps) raised a question of their reliability for further use. Moreover, as the risk and potential safety concern of the shut down reactors were not given priority attention primarily because of the false premise worlwide that "shut down" means "safe", urgent safety actions are needed. In all these circumstances, the future status of the "RA" reactor became a complicated,issue, a question the answer to it being a difficult task.

2. THE "RA" WITHIN WORLD RESEARCH REACTORS

The era of research reactors begun with the first criticality of Chicago Pile 1 on 2 December 1942. This facility was shut down after a few months only, but a vast new field of research reactor technology had emerged. The initial efforts were directed towards military uses and efforts to promote peaceful application of nuclear science and technology started a few years after the Second World War. The number of research reactors increased rapidly so that by the end of 1955 there were 40 operational research reactors, of which 31 were in the USA, 3 in the USSR, 3 in UK, 2 in Canada and 1 in France. Rapid progress was seen in the years 1956-1975, with Yugoslavia being among the first few developing countries to built such facilities (the first was the critical assembly "RB", operated since 1958). The year 1959 ended with 155 research reactors ("RA" included) in operation in 24 countries worldwide (including Yugoslavia), of which 97 in the USA alone. By 1961 the number of operational research reactors had increased to 173 in 31 countries, including 17 reactors in 14 developing countries. The peak was reached in 1975, when 373 reactors were operating in 55 countries. At this point the construction of new reactors begun to slow down and several reactors (primarily in industrialized countries), which had completed their goals or become uneconomical to operate, were shut down. While the number of operational research reactors in developing countries continued to increase, the world total started to fall, and this trend is continuing, as shown in a historical growth of the opeartional world research reactors on Figure 1.

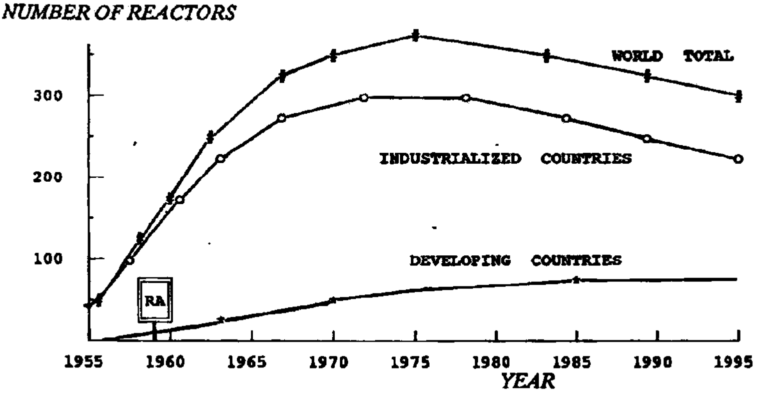

Figure 1: History of Operational Research Reactors in the World

Several factors begun to influence the operation of research reactors from the mid 1970s. It is useful to take a retrospective look at these issues in order to understand the present situation and to develop a practical and viable strategy for the future status of the "RA" research reactor. These issues reveal the worlwide situation as follows:

(a) Many research reactors were faced with severe budget cuts which forced the reduction of staff, a de-emphasis of basic research, reduced utilization and in some cases shut down of the facilities. The accidents at Three Mile Island in 1979 and at Chernobyl' in 1986 streghtened the anti-nuclear views in many countries. The safety of research reactors was subjected to critical review to satisfy the public demands. The declining financial resources were put under further pressure by the need to implement safety upgrades.

(b) The average age of currently operating research reactors is 27 years and more than 70% are over 20 years old. These older reactors were generally not built to specific nuclear standards. Safety analyses had to be performed afresh for renewal of their operating licences. The costs associated with the safety upgrades and with modernizing the old and absolete reactor equipment or instrumentation for research far exceeded the resources available.

(c) In the beginning most research reactors used highly enriched uranium fuel. In order to reduce the risk of proliferation, a programme of using low enriched uranium fuels was launched, with the first meeting held by the IAEA in 1979. New low enriched fuels have since been developed to replace the highly enriched fuels, but they are generally more expensive and significantly increase the operating costs. The conversion from highly to low enriched uranium has increased the amount of spent fuel to be stored or disposed off. Inadequate storage capacity and the need to license additional storage facilities could lead to the shut down of some reactors.

(d) Under the influence of the worldwide trend towards "privatization" of industries, many research reactors are expected to generate only a part of their operating costs. This invariably results in a reduction of basic research and an emphasis on revenue earning commercial programmes. The inability to meet these expectations leads to reduced utilization or even to shut down of the research reactors.

These problems have generally contributed towards shut down of many reactors in industrialized countries and have adversely affected their utilization in developing countries. Therefore, the IAEA is making concerted efforts to overcome these problems and to assist membes states in promoting the utilization of their research reactors, particularly in developing countries. Such an assistance and support was granted to Yugoslavia as well.

At present 57 countries in the world have operational research reactors and several more are in the process of establishing new facilities. To date, 693 research reactors have been built, or are under construction or planned worldwide. However, over 350 reactors have been shut down and decommissioned. According to the information available in the new (1996) IAEA Research Reactor Database (in it, 109 reactors were added to the figure of 584 in 1995 data base), there are only 290 operational research reactors in the world. That includes 91 reactors in 39 developing countries. There are 44 developing countries which have research reactors in operation or under construction, or that have immediate plans to establish new facilities, and another 5 which have reactors permanently shut down, while a few more have programmes for training a work force in anticipation of initiating some activity in the future. Table 1 presents the statistical data on the present status, reactor type and power range of the 693 world research reactors according to the IAEA Research Reactor Data Base, indicating the position of the "RA" reactor among them.

Table 1: STATISTICS OF WORLD RESEARCH REACTORS

Present Status	
Operating	290*
Shutdown	373
Under construction	11
Planned	17
Unknown	2

Reactor Type	
Pool	225*
Tank	144*
with Heavy Water	42
Homogeneous	40
Fast	30
Graphite	27
Other	227

Power Range:	
≤1kW.	239
1kW÷1MW	211
1MW÷5MW	80*
5MW÷10MW	46
≥10MW	100
Unknown	1

* "RA" included

3. DESIGN AND OPERATIONAL FEATURES OF THE "RA" REACTOR

3.1. Reactor Design Parameters

The "RA" is a thermal heavy water moderated and cooled research reactor of the "tank" type, designed and supplied by former USSR. The design power of the "RA" reactor was 6.5 MW for normal operating regime and 10.0 MW in forced regime. The average thermal neutron flux with nominal power was $6 \times 10^{13}\ m^{-2}s^{-1}$ and the maximum in the centre $10^{18}\ m^{-2}s^{-1}$. However, with new highly enriched fuel, the operating power is limited to 4.7 MW, while the maximum neutron flux is $9 \times 10^{17}\ m^{-2}s^{-1}$.

The reactor active zone is situated inside the inner aluminium reactor vessel, surrounded by the graphite reflector, the outer stainless steel reactor vessel and the biological shield of water and heavy concrete. The active core of the "RA" reactor is cylindrical, 1.40 m in diameter and 1.23 m high. The inner diameter of the reactor vessel is 1.405 m up to the height of 3.6 m, and above it 1.619 m. Radial wall thickness is 8 mm, with a double bottom thick 20 mm (upper plate) and 30 mm (lower plate). Total height of the outer vessel is 6.06 m, its wall thickness is 15 mm, while its diameter is 2.66 m in the lower part (around the graphite reflector) and 1.645 m in the upper part. Graphite wall between the inner and outer vessels is 0.60 m thick and 3.00 m high. Water shield comprises three separate parts, ordinary water shield ring 0.70 m thick, bottom water shield 0.40 m high, upper water shield with two side ring sections 2.00 m wide and 2.20 m high and a cover 1.80 m thick. Outer heavy concrete shield is 10.55 m high and 2.00 m thick. A cross sectional view of the "RA" reactor is presented in Figure 2.

The original fuel element is a hollow cylinder of 2% enriched uranium with aluminium cladding, 110 mm long with 37 mm outer diameter (Figure 3). The new fuel element is with 80% enriched uranium spread through the aluminuim lattice of the same dimensions and the content of ^{235}U is also the same (7.7 grams per element). It should be noted that the new (80%) fuel is unique, while for the old fuel (2%) there was a reference reactor in China. The TVRS reactor in Moscow is similar to the "RA" reactor, but it is not considered as reference one due to differences in power (2.5 MW), cooling system, reactor vessel design, quality and size of the radial reflector, the number and lattice of control rods etc. However, the experience with the same (80%) fuel in the TVRS reactor was used when the new fuel was purchased for the "RA" reactor.

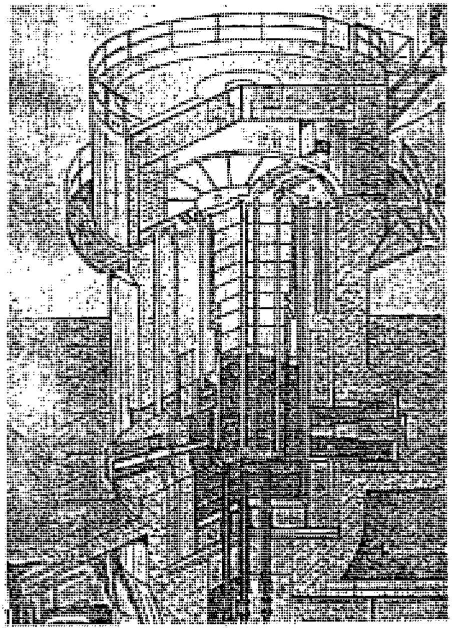

Figure 2: Reactor Cross Section

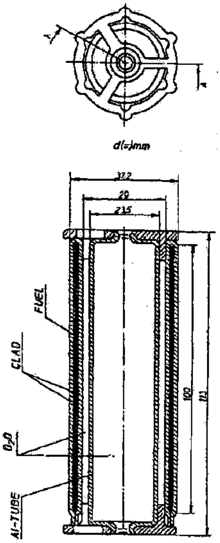

Figure 3: Fuel Element

The fuel elements are placed in an aluminium tube (11 elements per tube), thus forming a fuel channel. Maximum 82 channels form the square reactor lattice with 130 mm pitch. The fuel channels are aluminium tubes Φ 43/41 mm 5.456 m long, with an extension 113 mm long at the bottom, entering the hole at the bottom plate of the reactor inner vessel. The heavy water coolant is pumped from the bottom of the reactor vessel and upwards through the fuel channel on both sides of the fuel element and then down through the moderator into the outlet tube at the bottom of the reactor vessel.

Two cadmium safety rods are operated by separate mechanisms for automatic and immediate shut down (scram) of the reactor. Another two cadmium rods are used for an automatic control of reactor power, while seven cadmium rods are used for compensation of long term reactivity changes. Control and safety rods are inserted into the reactor core through aluminium channels, isolated from the primary circuit and filled up with helium when the reactor is in operation. The helium gas is kept at the upper part of the reactor vessel to prevent degradation of the heavy water as well as to collect explosive product of water hydrolysis and possible fission products in the case of an accident. Since the existing control rods are partially burned-out, particularly so in their lower active parts, the new stainless steel control rods, with gadolinium as burnable absorber, were purchased together with the new electronic control equipment.

Experimental channels are also made of aluminium. These channels are hermetically separated both from the reactor primary circuit and from the helium system. Five of them are arrannged in a square lattice of fuel channels, and four are outside this arrangement (one is used for the new core spray cooling system).

The waste heat from the heavy water and the graphite cooling systems is transfered to the Danube river via a secondary cooling system. For that purpose the secondary cooling water flow of 450 m^3/h is required. From a cooling water reservoir, four circuits are operated for cooling of the reactor primary circuit, system for dehydratation of the heavy water (18 m^3/h), graphite reflector (20 m^3/h) and pumps of the primary circulation loop and gas cooling system.

Power supply is provided from the national electric network via two independent lines, as well as from local emergency sources. The emergency sources apply two motor-generator groups with 110 V AC motors (fed by 110 V stationary bateries of 1600 Ah) and three-phase 400/230 V sinhronous generators of 80 kVA, as well as a diesel generator group 400/230 V of 313 kVA. The stationary bateries are also used with an inverter device of 40 kVA installed.

The control and safety system consists of three sub-systems: process control system (KIP), regulation and protection system (SUZ) and dosimetric control system (DOZ). The KIP is used to control the reactor and auxiliary technological parameters. The SUZ is used to regulate reactor power and time constant and to compensate the reactivity changes. The DOZ is composed of central dose-control system and stationary and portable dose-meters.

The reactor ventilation system is used to control the ambient air circulation and discharge to the environment. Operating pressure in the reactor building is kept well below the atmospheric pressure (the four zones are provided) to prevent any leakage of contaminated air to the environment.

The fuel handling system of the RA reactor includes a transporter above the reactor core, used for reactor fuelling, as well as for the transfer of fuel channels with irradiated fuel elements into a water channel connecting the reactor water shield and the temporary spent fuel storage pool. This systemm also includes a device for axial shufling of fuel elements (added in late 1960s), two cranes (one in the reactor hall and another in the spent fuel storage room) and a fuel handling machine for remote automatic manipulation of irradiated fuel. The spent fuel storage pool, consisting of four independent water basins 6.00 m deep with 0.40 m thick concrete walls, is filled with tubular stainless steel containers, receiving up to 11 fuel elements each, and aluminium barrels with repacked irradiated fuel elements, placed in two layers, one over another.

3.2. Operating Performance and History of the "RA" Reactor

The original reactor fuel was a 2% enriched uranium metal with aluminium cladding in hollow cilinder form, but from 1976 new fuel with 80% enriched uranium oxide dispersed in aluminium matrix is used. The new fuel element, having the same geometry and the same amount (7.7 g) of ^{235}U was expected to make it possible to increase the neutron flux due to lower parasitic absorption in ^{238}U. From 1976 to 1979 the reactor was operated with mixed 2% and 80% enriched fuel core. A considerable amount of fresh fuel is also placed in a dry storage room in the reactor building. Nuclear criticality safety studies performed for fresh and irradiated fuel at the reactor site proved that sufficient subcriticality is provided for all existing configurations.

Originally, it was planned that the irradiated fuel, after 4-5 years spent in the temporary storage pool, had to be transfered back to the USSR. Since this transfer has not been realized, in order to increase the spent fuel storage capacity, some of the oldest 2% enriched fuel had to be taken out of the tubular stainless steel containers and repacked in aluminium barrels, each containing 30 aluminium tubes, receiving up to 6 irradiated fuel elements per tube. Cadmium layers were introduced in the barrels in order to provide the necessary subcriticality. According to the reactor regulations, enough free space has to be provided in the spent fuel storage pool to make the emergency core unloading possible, if necessary. When the "RA" reactor was shut down in 1984, all the 48 fuel channels were left loaded with relatively fresh 80% enriched fuel.

In March 1979, during regular refuelling, oxidation deposits were noticed on the new fuel cladding, and the reactor was shut down. Along with the existing distillation system, an ion exchange system was introduced and both systems were used for heavy water purification. However, in spite of the regular purification of heavy water and completely new core with 80% enriched fuel, oxidation at the fuel cladding was noticed again, in 1982, after only one year of operation at a reduced power of 2.0 MW. The power of 4.7 MW was found to be the maximum allowed if the temperature of the fuel element cladding in the central channel is to be kept below the maximum permissible temperature of 90°C.

In the meantime, certain problems were also encountered with some other reactor systems. Due to vibrations of the heavy water pumps at 3000 rpm, their speed was reduced to 1500 rpm as early as in 1963. Also, a melting of the pump bearings caused contamination of the primary cycle by cobalt. Equipment maintenance problems were present for a long time, particularly with the old type electronic equipment, for which no spare parts could be obtained any more.

However, an evaluation by the IAEA mission performed in 1981 has shown that the "RA" reactor was around half of its useful life, and a decision was then made to redesign and upgrade the reactor systems. For that purpose the reactor vessel was thoroughly inspected by a specialized French company (using TV camera and ultrasonic equipment) and found to be in a fairly good condition and, in spite of the corrosion deposits formed on the inner surface in the active zone region, capable of operating for another 15 to 20 years.

After 1982 the reactor core was once more changed completely, but corrosion products were detected again. Since then, the reactor has never been operated at full power and in nominal working regime. For both, administrative and technical reasons, the reactor was shut down in August 1984 in order to reconstruct and improve all its vital systems. Non-existant emergency core cooling and emergency ventilation systems were built as required by the new licensing regulation imposed in the meantime. In addition, a new fuel handling machine, a new power supply system and a new water purification system for spent fuel storage pool were built. Also, a new experimental loop ("Vinča"-1) has been provided for the fuel testing and material irradiation experiments, while the existing experimental loops have been equipped with new measuring equipment (difractometers, spectrometers) to increase the experimental capabilities of the "RA" reactor.

In the course of modernization for the restart of the "RA" reactor, a large amount of new fuel elements was purchased in the former USSR. This amount of fuel is sufficient for another life time of continuous operation of the "RA" reactor. All new emergency systems (for emergency cooling of the reactor core, for emergency ventilation, for emergency power supply) were installed. Although a new irradiated fuel handling machine was completed, the software for its remote control is still missing. New system for purifying the water in the spent fuel storage pool was also completed, but has not been tested yet.

As the reactor control system had to be modernized, and a completely new system was granted by the IAEA through the technical assistance and support. Under this grant, a complete change of electronic equipment and instrumentation was contracted by the IAEA with a former USSR company, due to furnish all items needed by the end of 1990 and the total price (about 2.5 million US $) was paid by the IAEA. However, after only a partial delivery (89 out of 223 items are still missing), further deliveries have been suspended in October 1991, well before the economic sanctions of the UN Security Council were imposed on Yugoslavia. The old instrumentation and control system has been dismantled in the meantime in order to be replaced by the new one, but it was not completed yet.

4. ACTUAL STATUS AND VALUE OF THE "RA" REACTOR

4.1. Actual Status of the Reactor Equipment

A recent engineering inspection and evaluation of the current status of the shut down "RA" reactor has revealed its main features as follows:

- the reactor core is left fully loaded (contains 480 fuel elements of 80% enriched uranium of relatively low burnup), while the safety, automatic power control and long term reactivity compensation rods are all inserted in the core at the lowest possible position;
- all 5.3 tons of the heavy water has been drained from the primary circuit to the heavy water reservoir and the helium has been drained from the reactor vessel as well, so that the reactor vessel is filled with the air at the atmospheric pressure;
- the automatic power control system, the system for measuring the reactor parameters, as well as the system of radiation control and protection have been dismantled, with a part of new equipment delivered, but not installed;
- the old fuel handling machine has been replaced by new one, which is not operable since the software for remote automatic control is not available;
- the special ventilation system is operable, but could not fulfil emergency requirements because emergency filters are not installed and an underground portion of the ventilation tubes is damaged;
- a considerable portion of the secondary cooling water system pipes has also been damaged by corrosion and could hardly withstand the working pressure;
- the equipment for radiological control, meteorological measurement, operational and personal dosimetry and decontamination is technologically old fashioned and could therefore become unreliable;
- the reactor crew is reduced during the current long shut down period and, with very few exceptions, has no experience with an operating reactor.

The inspection of the reactor equipment has shown a considerable life expectancy for most of them. However, there is still much left to be done before it can be adapted to a reliable continued operation if the reactor is to be restarted. The adjstment and testing is necessary for the newly added equipment as well.

Heavy water purity is considered to be still acceptable for both moderator and coolant requirements; nevertheless, the availability of spare quantities is sufficient for total replacement if necessary. Graphite, as neutron reflector, is not expected to change, except for Wiegner energy, whose effect is cummulative and may influence the integrity of reflector structure.

Neither deformations nor swelling were noticed at the surface of fuel elements. However, corrosive deposits are present, particularly on the surface of the fuel elements that were longer used in the reactor (eg. in 1979) or have been less cooled (in peripheral fuel channels). It was also noticed that the resistance to the corrosion of highly (80%) enriched uranium fuel elements is less than of the low (2%) enriched ones.

The inner reactor vessel walls were noticed (through measurements of the thickness by ultrasonic tools) to be attacked by a slow corrosion process, whose causes have not been discovered yet. However, at the outer reactor vessel a crack was noticed in 1970 (which did not increase since), with consequent loss of vacuum between the two vessels.

The actual situation described above with the "RA" reactor as a "dormant" facility is considered intolerable, and an urgent action is required to modify this situation according to the modern reactor safety standards. Such an action is needed even before a decision could be made on the future status of the "RA" reactor and irrespective of this status. To support the decision making process on the subject, alternatives to the planned reactor rehabilitation and restart are involved and other options are considered, such as:

- continuation of the present status with an improved reactor safety;
- conservation to preserve the equipment from further deterioration; or
- final shut down and decommissioning.

All of the four options have their economic, safety and other advantages and drawbacks, which are beeing investigated at present and compared in order to select the most suitable solution (see § 5). An IAEA "facts finding" mission has visited "Vinča" Institute to evaluate the safety implications of the present situation of the "RA" reactor and suggested the possible safety measures. Some urgent measures at the spent fuel storage pool have been taken by the Yugoslav government but further international support and assistance are considered necessary.

4.2. Present Value of the "RA" Reactor

During an extensive refurbishment of the RA reactor, particularly intensified in 1980s, after governmental decision on its modernization, a considerable renewal was made of all its equipment, including new systems, that were not provided by the original design, but were found necessary to satisfy new safety requirement or operational needs. The reactor core has also been enlarged in comparison with the original design core by adding 40 new fuel elements (4 new fuel channels were added, giving total of 48 fuel channels). New shafts for the heavy water pump have been supplied by a local manufacturer, and some other spare parts provided as well. By all this new investment, the overall value of the "RA" reactor has been considerably increased, which has to be taken into account as well in decision making on its future status.

The value added includes mainly new equipment of instrumentation and control system, new spent fuel handling equipment, new emergency power supply, new special ventilation equipment, new emergency core cooling system and a new experimental loop "Vinča 1" for material testing. All of these new systems, except for the instrumentation and control system, have already been delivered and installed. Two of them, the emergency core cooling and special ventilation systems required by the licensing authorities, were installed first. The new emergency core cooling system includes a core spay circuit with heavy water and another spare circuit (for the case of failure of the first one) with ordinary water. New special ventilation system was added to the existing one to evacaute the air from the reactor hall, reactor room, spent fuel storage room and hot cells via special (absolute) filters and (in the case of emergency) active filters.

However, the new control system is still incomplete (total received is 65% of the contracted items, worth 83.9% of the total contracted cost). At present the following equipment have been received from the suppliers: all items for the SUZ system, all items for the DOZ system except for frames and power supply, a part of equipment for the KIP (62.5% of the scope, worth 37% of the total cost) and a part of cables needed (16% of the scope, worth 19.1% of the total cost of the cables). Still missing are the temperature sensors of different ranges, current transducers (19 pieces), indicators (44 pieces), as well as displays, frames, special cables etc.

Total value of the new installed equipment is 4,135,000 USD (1986). This value is thus added to the value of the existing equipment. As the initial value of the reactor "RA" in 1957 was about 7,570,000 USD (buildings and civil structures 2,375,000 USD and equipment, local and imported, 5,195,000 USD), this initial value at present (1986) is 41,689,855 USD (13,079,710 USD and 28,610,145 USD for buildings and civil structures and equipment, respectively). Taking into account depreciation rates of civil structures and equipment applied to the above initial value, the total actual value of the reactor "RA" was calculated to be 20,844,927 USD, of which 14,305,072 USD is the actual value of the equipment and 6,539,855 USD of the buildings and civil structures. Since the new systems and equipment have not been in use so far, their actual value is assumed to be practically equal to their actual initial value, 5,585,246 USD.

With the additional 2 tons of heavy water (worth 2,837,100 USD) purchased for the new emergency core cooling system and fresh fuel elements (worth 4,972,720 USD), the total actual worth of these items, ready for the future use, is about 7,809,820 USD. Thus, the overall actual value of the "RA" reactor is 34,239,993 USD. Of course, in the present circumstances, the use of such a valuable national resource presents an engineering and scientific challenge. It will, therefore, be taken into account in the comparative evaluation of possible options for the future status of the "RA" reactor.

5. OPTIONS FOR THE FUTURE STATUS OF "RA" REACTOR

5.1. Refurbishment for Re-start of the "RA" Reactor

Rehabilitation and upgrading of the "RA" reactor, based on the existing and new equipment, is considered to be a continuation of the earlier initiated process of refurbishment for further its use. The pricipal aim is an establishment of the operational status of the "RA" research reactor, intended to the production and use of radioisotopes, including neutron activation analysis and promotion of the basic and applied research as well as to the development of a qualified work force for modern technologies and other national interests.

All of these issues are also addressed in the IAEA's ongoing programmes to enhance exploitation of research reactors. These programmes focus on the same major areas: the production of radioisotopes, and the promotion of basic and applied research, education and training. Some of the IAEA's research reactor programmes cover global or regional issues or those pertaining to a class of reactors or specific subjects, while other programmes address the specific needs of individual facilities. To achieve such goals, new technologies and even materials are often available, which make it possible to considerably improve performances of the existing plants.

If continued, the process of refurbishment of the "RA" reactor for an extended use, would also lead to its considerable modernization as compared to the original design. It is well known that the rehabilitation of the existing plants of any type may prove to be an economically justified alternative for the new ones based on an advantage of such investment over the larger investment into the new plants owing to a presently high cost of capital. It is considered that any rehabilitation project includes improvements that would lead to an increase of reliability and availability, as well as to an upgrading of the capacity and working performances, including better safety and environmental protection performances. This applies equally to the refurbishment of the "RA" reactor.

Research reactors involve very large investments and possess a great potential for research and development in various disciplines. In a developing country as Yugoslavia, a research reactor centre such as Vinča Institute is generally a centre for high level research, training and education, which are often not available elsewhere in the country. It is therefore important that the facilities be effectivelly utilized, utilization programmes have to be planned according to the size, power level and specific features of the reactor, but in most cases major uses comprise the production of radioisotopes, basic and applied research, and training and development of human resources.

Production of radioisotopes is considered to be a continuation of the earlier use of the "RA" reactor. Regardless of their ultimate utilization, be it for industry, medicine or agriculture, radioisotopes are produced in nuclear research reactors and in charged particle accelerators, particularly cyclotrones. It is a historical fact that the practical application of both of these machines was first demonstrated by the production of artificial radioisotopes. (Research reactors have been used for the production of radioisotopes since the 1940s). A variety of radioisotopes produced included those which offered good potential for biomedical investigations in nuclear medicine as a new, emerging specialized field of medicine. The experience gained with "RA" reactor is very good.

It is interesting to note that in many instances one of the most effective arguments used to justify government funding for the construction and operation of a research reactor was the need to produce radioisotopes for various applications relevant to the national economy. The same argument is still used to justify the continuation of operation of some research reactor facilities. Particularly in developing countries, many research reactor facilities are engaged in the production of radioisotopes to satisfy (at least partially, and in a few cases totally) the national demand for radioisotopes.

Practically all the nuclear research reactors in developing countries maintain active radioisotope production programmes. The IAEA has co-operated to strenghten those programmes by upgrading laboratory facilities, hot cell technology and instrumentation for quality control as well as providing training and expert services. In addition, a new IAEA programme on optimization of reactor irradiation strategies and development of the corresponding target technology for the production of therapeutic radioisotopes was launched in 1993. The results obtained thus far are quite encouraging, demonstrating the practicability of medium neutron flux research reactors for the production of radioisotopes as potential therapeutic agents for medical applications.

Radioisotopes have been used as tracers in almost all branches of science and technology. In terms of quantity, the major use is in the field of nuclear medicine and industry. Two typical examples are ^{131}I, used since the early days of radioisotope application in medicine for the treatment of thyroid disorders, and ^{60}Co, used as a powerful source of gamma radiation, both for radiotherapy and for the gamma irradiation of several industrial products, including food. Both of these radioisotopes are produced by neutron irradiation of appropriate targets placed in research reactors, although large scale production of ^{60}Co is better achieved in nuclear power reactors. The current radiotracer of choice for diagnostic nuclear medicine investigations is an isotope of an artificial element, ^{99}Tc^{m}, and a decay product of the element ^{99}Mo, which is also produced in nuclear research reactors.

The IAEA programmes for the promotion of research, education and training focus on the identification of the causes of underutilization of research reactors and assist in resolving problems and promoting new techniques and technologies. Efforts are also directed towards improving the operation and management of the reactors and upgrading the experimental facilities. This is achieved through technical assistance and research reactor programmes of the IAEA. Additionally, the reactors and experimental facilities have constantly been upgraded to avoid absolescence, to satisfy the prevalent, more stringent safety regulations and to gain public acceptance. Their utilization had to be optimized and their operating costs minimized due to declining government funding. The current research reactor programme of the IAEA aims to increase utilization of research reactors, and in particular, to assist developing member states to exploit the potential of their research reactor facilities.

5.2. Conservation to Preserve the Integrity of the "RA" Reactor

If an immediate decision on the future status of the "RA" reactor could not be made, its conservation is considered to be the only reasonable alternative. Until a decision is made on the plant start up or on its permanent shut-down, its conservation will preserve the plant from degradation during such a temporary (non operational) shut down. Of course, such an option can not be considered final, and further investigation on the final status should be carried out.

By conservation, instead of an immediate use, a postponed use is made possible, thus preserving, the existing value of such an important national resource. The prevented degradation of the equipment is important not only for an eventual start up, but also for a preservation of integrity of the structures and safety while waiting for the conditions for a safe decommissioning to be achieved (lowered dose level, selected disposal site for highly radioactive wastes, etc.).

The safety concern is of prime importance in conservation option as well. For many years the focus of safety analysis and regulatory attention worldwide was on the safety margins and accident scenarios associated with the routine operation at full power. The risk and potential safety concerns while the plant was shut down (or at low power) were not given priority attention primarily because of the false premise that "shut down" means "safe". However, the situation has changed substantially in recent years, because a number of significant events have occurred just while plants were shut down. Therefore, special conditions and risks during shut down have received specific attention.

5.3. Final Shut-Down and Decommissioning Option

If decision is not to use the equipment any more, but to finally shut down and (immediately or later) dismantle the reactor, it may prove to be very expensive option. Out of many possible alternatives of final shut-down of nuclear facilities, the following two main categories may be considered: early dismantling (in less than 10 years after the shut-down) or safe enclosure until a latter (postponed) dismantling. The first option is somewhat chiper, but much more inconvenient from the radiation protection point of view. The second option may also have many disadvantages, and is, therefore, possible to optimize such a decision for the reactor shut down with respect to the most suitable time and programme of decommissioning. Needless to say that the decision for decommissioning strategy must also be in full conformance with the licence issued by the governmental regulatory body.

In selecting of a decommissioning strategy, the "safe enclosure" option is usually considered first, since developing a strategy to decommission a given nuclear installation is not a straightforward exercise, and a multitude of different factors, concerns and constraints affect the decision making process (in practice, no two cases are identical). Whatever approach within the variety of possible strategies (early dismantling, safe enclosure and deferred dismantling, etc.) is chosen, current experience shows that total dismantling takes place with a significant delay after final shutdown in many cases. Even in a country such as Japan, where the national policy dictates early dismantling, five to ten years after final shutdown are deemed necessary to make preparations. Also, dismantling activities may continue for a number of years. Significant delays are proposed in most countries and may result in a deferral period lasting up to and over one hundred years, during which time the "dormant" facility must be maintained in a safe condition.

Until a few years ago, the technical experience gained from decommissioning was mainly related to first-of-its-kind projects. Since the number of decommissioning projects has increased, considerable additional experience has been accumulated, thus providing general conclusions on decommissioning techniques for different types of research reactors (to date, over 350 research reactors have been shut down and decommissioned worldwide). By the turn of the century, about 220 research reactors operating today will have reached 30 years and will also become probable candidates for decommissioning, many of these reactors being located in the countries like Yugoslavia, where decommissioning experience is not readily available.

Obviously, a particular decommissioning strategy should be based upon a careful trade-off between advantages and disadvantages, leading eventually to a decision on an optimal timing and scheduling for dismantling. Activities are already under way at the IAEA to provide guidance and practical recommendations on the selection of a decommissioning option and the necessary technical conditions to ensure safety at a "dormant" facility. Should this be an option for the "RA" reactor, such guidance and international support will also be necessary.

6. SUMMARY AND CONCLUSION

After many years of its exploitation (since December 1959) and several forced outages, the "RA" reactor at the Vinča Institute was shut down in August 1984 and has not been in operation since then. In the meantime, the safety systems for emergency core cooling and for special ventilation were built as required by the licensing authorities, but the reactor was not started again, since the existing control systems have been desintegrated for the replacement by new ones, which have not been completed yet. However, the present status, as well as a repeated appearance of the corrosion on certain components which brought their reliability for continued operation in doubt, made the future status of the "RA" reactor an open question, and its planned restart has to be reexamined.

A degradation of the "RA" reactor systems in its present status is in progress, faster than it could be if, upon the shut-down, these systems would have been protected by conservation. Certain irregularities are also present at the reactor, which should be eliminated for its more safe and secure control even under the present "dormant facility" status.

The present status of the "RA" reactor has negative repercusions on financing by the government, as its further use for experimental and commercial purposes is dubious. Instead of carrying out the earlier programme of starting the reactor again, other possible options are also considered, such as conservation of the reactor to preserve it from further degradation or final shut-down and decommissioning. To arrive at an optimum solution, these options are expected to be compared to each other taking into account present intolerable safety conditions as well as a considerable value of the reactor in terms of money and of technological and scientific significance.

Additionally, due to an increased attention paid at present to the nuclear technology in general, whose manipulation and possibility of mis-use increased with the destruction of former systems in Eastern Europe, the present status of the "RA" reactor proved to be unsatisfactory from the physical security point of view. The safety and physical security issues of the "RA" reactor may also be addressed, taking into account the vicinity of the large population centre such as Belgrade. Thus, a particular form of degradation of this unique national resource may be by its public rejection (as it has already been demonstrated by the anti-nuclear laws in Yugoslavia, Austria, Italy, Sweden and elsewhere), if extended to all nuclear technologies, including research reactors. Particular pressure of the public, as well as of business and polytical circles, is directed towards the nuclear installations supplied by the former USSR, requiring their closure or considerable renewals according to the western standards of nuclear safety.

In the presence of the above circumstances, the "RA" research reactor at the Vinča Institute is both an engineering and scientific challenge and a complicated political issue. As any other national resource, it should be the subject of a thorough evaluation of the feasibility of either its use (if the need and possibility exist) or of further preservation (if its latter use is probable), or refusal (if not). Specific features of such a resource are its permanent ageing (both, technological and human) and physical degradation by which the value of this resource is being irreversibly lost. On the other hand, the risk of a reduced safety increases, thus making this loss even faster. All these features make the issue of the future status of the "RA" ractor more urgent, and the challenge to the engineers and scientists to find the best solution for it even greater.

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