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European Nuclear Society
avenue des Arts 56
1000 Brussels, Belgium
Phone + 32 2 505 30 54
Fax +32 2 502 39 02
E-mail ens@euronuclear.org
Internet www.euronuclear.org

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New Projects

THE JULES HOROWITZ REACTOR : A NEW HIGH PERFORMANCES EUROPEAN MTR (MATERIAL TESTING REACTOR) WITH MODERN EXPERIMENTAL CAPACITIES - BUILDING AN INTERNATIONAL USER FACILITY

J. ESTRADE[1] - G. BIGNAN[1] - X. BRAVO[2]
[1] *CEA-DEN-DER-F-13108 Saint-Paul lez Durance*
[2] *CEA-DEN-DISN-F-91191 Gif sur Yvette*

Corresponding author: jerome.estrade@cea.fr

ABSTRACT

The Jules Horowitz Reactor (JHR) is a new Material Testing Reactor (MTR) currently under construction at CEA Cadarache research centre in the south of France. It will be a major Research facility in support to the development and the qualification of materials and fuels under irradiation with sizes and environment conditions relevant for nuclear power plants in order to optimise and demonstrate safe operations of existing power reactors as well as to support future reactor design. It will represent also an important Research Infrastructure for scientific studies dealing with material and fuel behaviour under irradiation.

The JHR will contribute also to secure the production of radioisotope for medical application. This is a key public health stake.

The construction of JHR which was started in 2007 is on-going. The criticality of this facility is planned end of 2016 and first experiments are expected in mid-2018. The design of the reactor will provide an essential facility supporting the programs for the nuclear energy for the next 50 years.

JHR is designed to provide high neutron flux (enhancing the maximum available today in MTRs), to run highly instrumented experiments to support advanced modelling giving prediction beyond experimental points, and to operate experimental devices giving environment conditions (pressure, temperature, flux, coolant chemistry, …) relevant for water reactors, for gas cooled thermal or fast reactors, for sodium fast reactors, …So, the reactor will perform R&D programs for the optimization of the present generation of NPP, support the development of the next generation of NPP (mainly LWR) and also offer irradiation possibilities for future reactors.

In parallel to the construction of the reactor, the preparation of an international community around JHR is continuing; this is an important topic because, as indicated in the introduction, building and gathering a strong international community in support to MTR experiments is a key-issue for the R&D in nuclear energy field. Consequently, CEA is welcoming scientists, Engineers (called Secondee) from various organisations/institutes who are integrated within the JHR team for a limited period of time (typically one year) for various topics such as physics studies for the development of the experimental devices (core physics, thermo-hydraulic…) and/or in support to the future Operator (Safety Analysis, I-C&C…).

This paper gives an up-to-date status of the construction and of the developments performed to build the future experimental capacity and will introduce examples of collaborations with secondees.

1. Introduction

European Material Testing Reactors (MTR) has provided an essential support for nuclear power programs over the last 40 years within the European Community. However, these Material Test Reactors (MTRs) will be more than 50 years old in this decade and will face increasing probability of shut-down due to the obsolescence of their safety standards and of their experimental capability. Such a situation cannot be sustained long term since “nuclear energy is a competitive energy source meeting the dual requirements for energy security and the reduction of greenhouse gas emissions, and is also an essential component of the energy mix” [1].

Associated with hot laboratories for the post irradiation examinations, MTRs are structuring research facilities for the European Research Area in the field of nuclear fission energy.
MTRs address the development and the qualification of materials and fuels under irradiation with sizes and environment conditions relevant for nuclear power plants in order to optimise and demonstrate safe operations of existing power reactors as well as to support future reactor design:

- Nuclear plants will follow a long-term trend driven by the plant life extension and management, reinforcement of the safety, waste and resource management, flexibility and economic improvement.
- In parallel to extending performance and safety for existing and coming power plants, R&D programs are taking place in order to assess and develop new reactor concepts (Generation IV reactors) that meet sustainability purposes.
- In addition, for most European countries, keeping competences alive is a strategic cross-cutting issue; developing and operating a new and up-to-date research reactor appears to be an effective way to train a new generation of scientists and engineers.

The Jules Horowitz (JHR), Material Testing Reactor, is one of answers for the needs of future research infrastructure in Europe.

JHR will be operated as an international user’s facility on the CEA Cadarache site. It will be dedicated to materials and fuel irradiations for the nuclear industry or research institutes and to radio-isotopes production for medical applications.

The design of this facility allows an important flexibility in order to comply with a large range of experimental needs, regarding the type of samples (fuel or materials), neutron flux and spectrum, type of coolants and thermal hydraulics conditions (LWR, Gen IV,…), in accordance with the scientific objectives of the programs. These experimental tools are under development and some of them will be available at JHR start up.

2. Organization arround JHR

2.1 JHR Consortium

The JHR, as a future international User Facility, is funded and steer by an international Consortium gathering today 10 partners from industry (utilities, fuel vendors…) and public bodies (R&D centres, Technical Safety Organizations TSO, regulators…):

- SCK•CEN from Belgium,
- CIEMAT from Spain,
- VTT from Finland,
- UJV-NRI from Czech Republic,
- VATTENFALL from Sweden,
- DAE from India,
- CEA,
- AREVA and EDF from France,
- JRC from the European Commission,
- IAEC from Israel.

UK will be joined as a futur member of JHR consortium during this year.
There is also an associated partnership with JAEA, through an implementing agreement with CEA.

Till JHR start-up, this list may still be enlarged as discussions are in progress with several countries interested in joining the Consortium. CEA is in charge of the construction of the reactor and will be the Nuclear Operator.

2.2 In-Kind contribution

It is interesting to quote that some members of JHR Consortium have an in-kind contribution. As some examples:

- CIEMAT who represents a domestic Spanish Consortium is designing and launching, as its main in-kind contribution, the manufacturing of the three heat exchangers of the primary circuit,
- VTT who represents a domestic Finnish Consortium is designing and manufacturing, as its main in-kind contribution, an underwater non-destructive examination bench [8],
- SCK•CEN, as its main in-kind contribution, is performing JHR fuel element qualification under irradiation in the EVITA loop,
- NRI is designing and manufacturing JHR hot cells,
- IAEC is performing the preliminary design of the LORELEI safety loop able to implement LOCA-type tests on a single LWR experimental fuel rod,
- DAE is in discussion with CEA for designing a LWR corrosion loop in the reflector for clad corrosion materials and Stainless Steel IASCC (Irradiation Assisted Stress Corrosion Cracking).

3. The JHR irradiation capability within the international context

The JHR will be a major experimental infrastructure to meet industrial and public needs. As a modern irradiation capability, it aims at answering the above expressed needs and is designed to provide high neutron fluxes (enhancing the maximum available today in European MTRs), to run highly instrumented experiments on a separate effect strategy, to support advanced modelling for a broader prediction capability and to operate experimental devices giving environment conditions (pressure, temperature, flux, coolant chemistry…) relevant for the nuclear power systems being optimized or to be developed.

The development of relevant irradiation systems raises challenges concerning not only the irradiation devices and the associated on-line measurements, but also the non destructive examination benches, the examination and handling hot cells and the analysis laboratories (fission product laboratory, chemistry laboratory etc.). These support systems play a crucial role to gain quickly reliable data on the sample, sometimes no more accessible after a long delay or transportation, and to enhance strongly the MTR experimental process quality.

In parallel to the construction of the reactor, the preparation of an international community around JHR is continuing.

Moreover, as another important objective, the JHR will contribute to secure the European production of radioisotope for medical application (25% of the European demand on a nominal level, up to 50% in case of specific request). This point is considered as a key public health stake.

3.1 A modern facility with a large area dedicated to experiments

The Nuclear facility comprises a reactor building with all equipments dedicated to the reactor and experimental devices and an auxiliary building dedicated to tasks in support for reactor and experimental devices operation.

The reactor building (see Figure 1) is designed to provide the **largest experimental capacity** possible with the largest **flexibility**. One half of this building is dedicated to the implementation of equipments in support to in-pile irradiations (for example, water loops). This corresponds to 700 m2 over 3 floors for implementation of experimental cubicles and 490 m^2 over 3 floors for instrumentation and control equipments. A supplementary area is devoted to analysis laboratories.

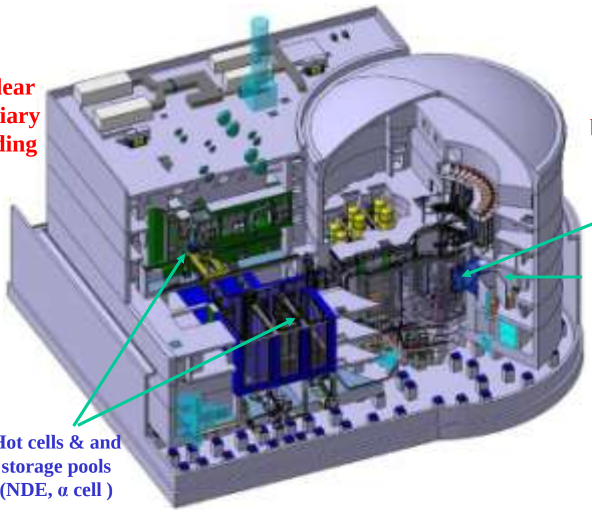

Figure 1. View of the JHR facility

3.2 A powerful reactor with numerous irradiation sites and irradiation conditions

The design of the reactor (see Figure 2) provides irradiation positions located either inside the reactor core with the highest ageing rate (up to 16 dpa/year for operation at 100 MW) or in the beryllium reflector area surrounding the core, with the highest thermal neutron flux. Numerous locations are implemented (up to **20 simultaneous experiments**) with a large range of irradiation conditions:

- 7 in-core locations of small diameter (32 mm) with a high fast flux (up to $5{,}5.10^{14}$ $n.cm^{-2}.s^{-1}$ perturbed flux above 1 MeV),
- 3 in-core locations of large diameter (80 mm) with a high fast flux (up to 4.10^{14} $n.cm^{-2}.s^{-1}$ perturbed flux above 1 MeV),
- 20 fixed positions (around 100 mm of diameter and one location with 200 mm) with a high thermal flux (up to $3{,}5\ 10^{14}$ $n.cm^{-2}.s^{-1}$ perturbed flux),
- 6 positions located on displacement devices located in water channels through the Beryllium reflector.

A typical reactor cycle is expected to last 26 days, and operation schedule could consist of 10 reactor cycles per year.

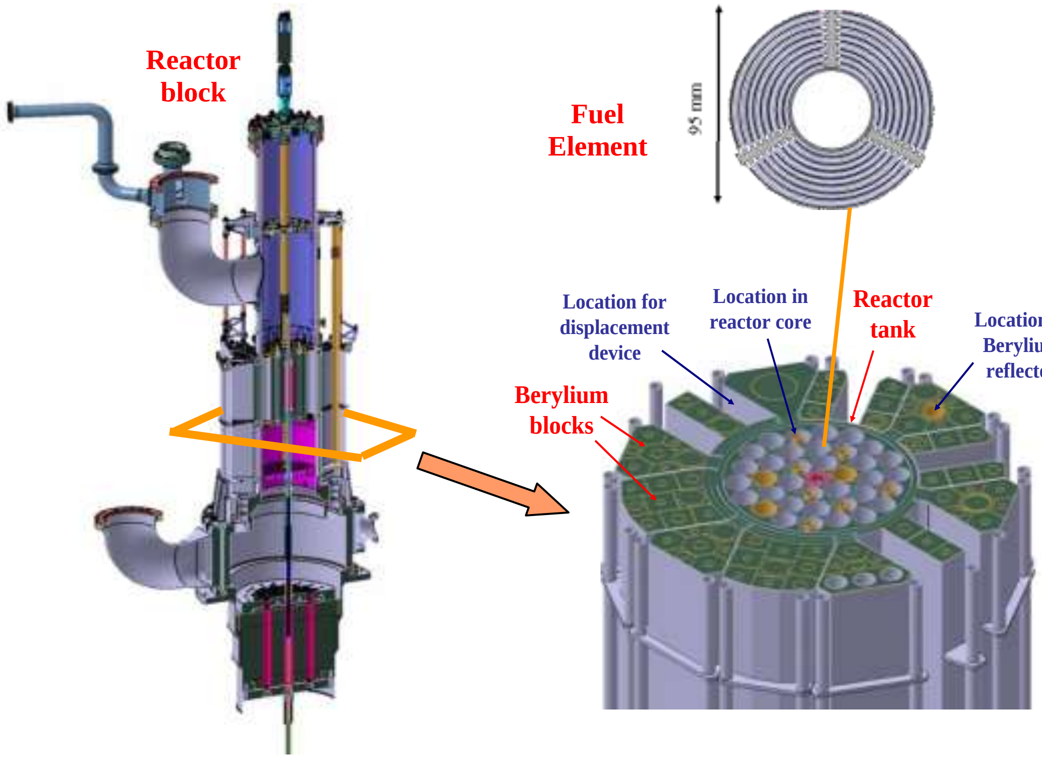

Figure 2. View of the reactor core with experimental locations

3.3 Collaborations with secondees around JHR

Building an International User Facility around JHR infrastructure, in parallel to the construction of the reactor, is also a major key issue. The preparation of an international community around JHR is continuing; this is an important topic because, as indicated in the introduction, building and gathering a strong international community in support to MTR experiments is a key-issue for the R&D in nuclear energy field. Consequently , CEA is welcoming scientists, Engineers (called Secondee) from various organisations/institutes who are integrated within the JHR team for a limited period of time (typically one year) for various topics such as physics studies for the development of the experimental devices (neutron physic, thermo-hydraulic…) and/or for support to the future Operator (Safety Analysis, I-C&C…).

4. JHR update status

The construction of JHR which was started in 2007 is on-going. Significant progress on civil works was achieved in 2012. The criticality of this facility is planned end of 2016 and first experiments are expected in mid-2018.

Figure 3 : View of the Building site march 2013

5. JHR Safety

The JHR incorporates the safety analysis right from the design phase, based on a modern reference system and methodology; in particular similar to those used in present projects such as the EPR, GEN3 NPPs, under construction in Finland, China and France.
The JHR Safety approach has been presented in detail at the IAEA General Conference on Research Reactors in Rabat November 2011 and some examples of incorporating Safety from the design phase are described in this reference [7].
The methodological safety approach for the JHR described in [7], is highlighting various innovative aspects and the specific design features of the new experimental reactor. Moreover, some of the initial design choices and options are detailed, coming directly from this innovative approach and feedback from existing reactors.

6. Conclusion

The JHR facility, currently under construction in the framework of an international consortium, is already open - regarding the experimental capacity - and will be more and more so to international collaboration. Its operation will provide a key infrastructure in the European and International Research Area for R&D in support to the use of nuclear energy.

7. References

[1] The Green Paper, “Towards a European Energy Security Strategy”, published by the European Commission in November 2000

[2] FEUNMARR, Future European Union Needs in Material Research Reactors, 5th FP thematic network, Nov. 2001 – Oct 2002

[3] The Jules Horowitz Reactor Project:” A new High Performances European and International Material Testing Reactor for the 21st century”- G. Bignan, D.Iracane

Nuclear Energy International publication (NEI-Dec 2008)

[4] “Sustaining Material Testing Capacity in France: From OSIRIS to JHR”
G. Bignan, D. Iracane, S. Loubière, C. Blandin CEA (France) IGORR 2009 Conference (Beijing)

[5] The Jules Horowitz Reactor: A new European MTR (Material Testing Reactor) open to International collaboration: Description and Status
G.Bignan; P. Lemoine; X. Bravo CEA (France) –RRFM 2011- Roma

[6] “The Jules Horowitz Reactor: A new European MTR open to International collaboration”
Gilles Bignan et al, IGORR 2010 (Knoxville TN –ORNL- September 2010)

[7] The Jules Horowitz Reactor: A new European MTR (Material Testing Reactor) open to International collaboration: Update Description and focus on the modern safety approach.
G. Bignan et al – IAEA International Conference on Research Reactors: Safe Management and Effective Utilization (Rabat- November 2011)

[8] : Non-destructive examination development for the JHR material testing reactor (C. Roure, B. Cornu, E. Simon, N. Estre, B. Berthet, P. Kinnunen, P Kotiluoto) – ANIMMA 2013

PUBLIC PERCEPTION ON NUCLEAR RESEARCH REACTORS IN NEW COMER STATES: A CASE STUDY FROM JORDAN

ABU QDAIS H. A.

Civil Engineering Department, Jordan University of Science & Technology,

Po,Box 30,30 Irbid, 22110, Jordan

MALKAWI S. R.

Nuclear Engineering Department, Jordan University of Science & Technology,

Po,Box 3030 Irbid, 22110,, Jordan

MALKAWI A. I

Civil Engineering Department, Jordan University of Science & Technology,

Po,Box 30,30 Irbid, 22110, Jordan

ABSTRACT

In many countries, the public opinion on nuclear energy became more negative after the Fukushima Daiichi accident. In new comer states, where nuclear energy programs are still in the development stage, the public perception was most affected. Therefore, siting new nuclear facilities becoming increasingly difficult. This is the case in Jordan, where the Jordanian Government has embarked on an ambitious program to build the capacity of the country in nuclear energy.

In order to relive the country from energy import which absorbs 25% of the GDP, the Jordanian nuclear program is aiming at building the national nuclear capacity through the construction of nuclear power plants, as well as a nuclear research reactor. The present paper is focusing on the issues of public perception and involvement in siting the first 5 MW Jordan Research and Training Reactor (JRTR), which the Jordan Atomic Energy Commission (JAEC) decided to build at the Jordan University of Science and Technology (JUST) Campus. The main objective of the JRTR is to provide training for nuclear engineers and scientists who will manage the country's nuclear energy program in the future.

The selected JRTR site within the campus of JUST is located in Ramtha province near by the town of Ramtha in northern Jordan. Since the announcement of JAEC about the intention of building the JRTR at JUST campus, several concerns were expressed by Ramtha community groups about the potential risks of the proposed JRTR project on the environment, as well as on the public health. Due to the absence of sufficient regulatory framework on how to involve the public in the site selection for such facilities, the construction of the JRTR on JUST campus started without adequate communication with the public. This has led to stronger opposition from the side of the Ramtha community, to build the project near by their town and on the land that used to belong to their tribes before being acquired by the Government.

JUST has led efforts to initiate communication with representatives from Ramtha local community. The paper is presenting the framework that JUST adopted to create a platform of dialog between the local community and JAEC. Recommendations on how to address people concerns and reflect the public views in siting such projects in a more informed and strategic manner were suggested.

1. Introduction

Many countries around the world consider research reactors as an essential step towards building their first nuclear power plants (NPPs). Nowadays, research reactors are playing a vital role in the progress of peaceful uses of nuclear energy.

Although most of the nuclear facilities are carrying real risks, not all nuclear projects are having the same degree of risks. In most of the cases, the public however do not differentiate between projects with low and high risks and perceive them as being equally dangerous (1). The syndrome of Not in My Back Yard (NIMBY) is common with such facilities, where people donot desire to host such facilities in the vicinity of their communities.

Decisions regarding siting and constructing of nuclear facilities are no longer the domain of closed community technical experts and facility executives (2). For new research reactors, it is important to accurately identify the stakeholders and detailing their needs and expectations. Surveys of public opinion to determine the degree of knowledge and receptiveness to research reactor projects are of great importance for the sustainability of the project. Furthermore, IAEA recommends to develop public information tools that respond to public enquiries and to explain the benefits of the research reactor (2).

The relationship between owners and operators of nuclear facilities and the public has received little attention (3). In their paper to IAEA, Richardson and Rickwood provided a brief overview of five cases of varying relations between nuclear facilities and the public. The study concluded that, there are tangible benefits to be gained from a more frank and transparent relationship between the nuclear power industry and the public. Such involvement will lead to enhancement of safety(3).

The Fukushima accident in March, 2011 has severely affected the growth of civilian nuclear power in many countries. After the accident, the public protests against nuclear power have been widened and became more intense. (4). As the public confidence after the accident has been eroded, the nuclear industry has to reconsider and review its engagement with the public.

More engagement with the public in a formal process that accepts and respects their views represents an immediate step that the nuclear industry can take will lead to building confidence, and can contribute to increased safety. Public education and outreach are of great importance in this regard (5).

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2. Jordan Research and Training Reactor

Jordan is a non producing oil country. About 97% of the country's energy need is being satisfied through import. During the the year 2012 the energy bill has been increased by 24% and amounted to 4.41 billion JD (6.2 billion US$) (6) which accounts for 25% Jordan's annual GDP. In an effort to diversify the country's energy sources, the Jordanian Government has embarked on an ambitious program to build the capacity of the country in nuclear energy. One component of such a program is to build a 5 MW Jordan Research and Training Reactor (JRTR). The project proponent Jordan Atomic Energy Commission (JAEC) has decided to build the JRTR at the Jordan University of Science and Technology (JUST) Campus as shown in Figure 1. The main objective of the JRTR is to provide training for nuclear engineers and scientists who will manage the country's nuclear program in the future. In addition, isotopes production will be taking place at JRTR. A consortium comprising the Korean Atomic Energy Research Institute and Daewoo Engineering and Constructions has been awarded a contract to build the JRTR. The reactor is a pool type one with nominal power of 5 MW.

One of the key aims of the Jordan's nuclear programme is to serve as a model in the region for the safe use of nuclear power and for implementing the program in a transparent manner. The country's commitment to transparency is the only viable approach that will ensure international acceptance and credibility for Jordan's nuclear program (7).

According to Jordan White Paper on Nuclear Energy in Jordan, which was issued by JAEC in 2011 (7), JAEC will create an environment of open and transparent dialogue with all stakeholders by adopting "engage, interact and cooperate" process. The White paper emphasized the need for transparent communication with the general public to get them involved in the decision making process at all stages of the nuclear projects. To disseminate information to the public, JAEC will issue booklets, provide internet sites and establish information centers as well as organizing trips for public representatives to certain nuclear facilities in other countries.

Although in the Jordanian regulations contain certain articles regarding the public involvement in decision making, there is however a lack of well identified tools and mechanisms for involving the public in siting complex projects like nuclear ones. Despite this, JAEC invested a lot of efforts to get the public involved in the decision making process to build the first of its type nuclear power plant in Jordan. This was not the case with the JRTR, where the site was identified long time ago within JUST campus, even before the establishment of JAEC.

3. Regulatory and Institutional Frameworks

As for the JRTR, there are two main entities who are playing major role in licensing the project, namely Jordan Nuclear Regulatory Agency (JNRC) and the Ministry of Environment (MOENV) .

Law No. 52, for the year 2006 is the primary legislation that addresses environmental protection issues in Jordan. The law specifies that the MOENV is the responsible authority for the protection of environment. It provides the MOENV with all judicial powers needed for implementation.

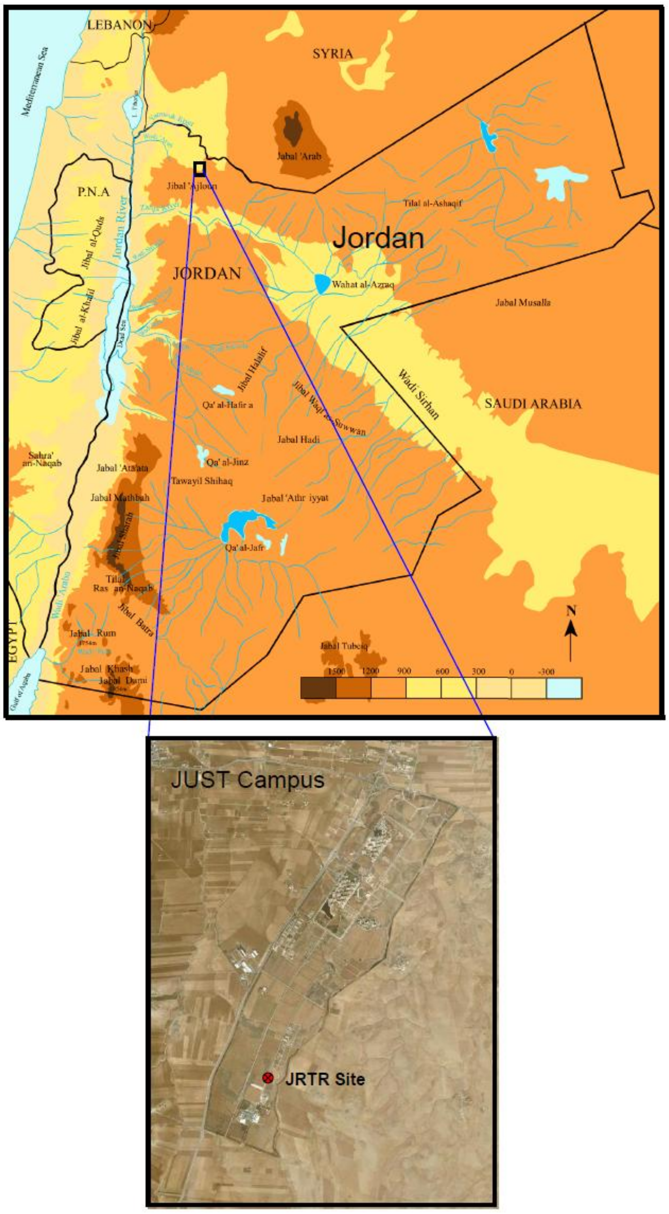

Figure 1. Jordan Research and Training Reactor within JUST campus (JAEC,2010)

Environmental Impact Assessment Regulation Number 37, for the year 2005 which was issued based on the environmental Law, specifies that there is a need for environmental impact assessment (EIA) study to be undertaken for nuclear facilities. An EIA report has to be prepared and approved by the concerned EIA committee at the MOENV. The EIA regulation specifies the public involvement in the process of decision making as a necessary step in the EIA study as shown in Figure 2.

The Jordanian government has acknowledged the critical role of public acceptability of nuclear energy options; however the regulatory framework to get the public involved in a systematic and institutionalized manner is not there. To date, nuclear energy has not been a topic of any opinion surveys. There are no quantitative studies on how people might be responding to siting such facilities like the nuclear power plant and JRTR.

The current public opposition to nuclear power in Jordan cannot be isolated from the public up-rises in the Arab World (Arabic Spring), which took place in many countries around Jordan. In Jordan the expression took place in a peaceful and organized manner, through demonstrations, strike and public hearings and seminars. There is a need for better communication and education programs that aim to provide a socially informed approach.

In 2001, the Nuclear Energy and Rdiation Protection Law No. 29, was issued. This law has paved the road for establishing Jordan Nuclear Energy commission. In July 2007, this law was replaced by two laws that established two independent entities, namely Law no. 42, for the establishment of JAEC and law no. 43 for the establishment of JNRC. The two laws made a clear separation between JAEC as promoter and developer of nuclear power projects, and JNRC as a regulatory agency responsible for nuclear safety (7).

Draft guidance for the review of the Environmental Impact Assessment, has already prepared by JNRC for radiation-related impacts, which fully complies with IAEA requirements and best international practices.

As a regulating agency, responsible for regulating and controlling the use of nuclear energy and ionizing radiation, one of the main duties of JNRC is to review license and permit applications for constructing and operating nuclear facilities in Jordan. In case the application is satisfying the safety requirements, the license or permit are granted.

4. EIA Study and Public Involvement

According to MOENV requirement JAEC has to subject the JRTR project to an Environmental Impact Assessment (EIA) study. JAEC has contracted Queen Rania Al Abdalla Center for Environmental Science and Technology (QRACEST) to carry out the EIA study. QARACEST is under the umbrella of JUST which hosts the first nuclear engineering program and where the JRTR is currently under construction.

As one of the important components of the EIA study is the public involvement, JUST has initiated contacts with the public in Ramtha town, which is the center of Ramtha Province and the most closely population center to the project site. Several steps and approaches were followed in communication with the public.

At the beginning a meeting with representatives of the community in Ramtha town was held. The first meeting revealed that there is a misunderstanding with respect to the JRTR project. Many of the community representatives attended the meeting had the perception that a huge nuclear power plant is to be built in the vicinity of their community. They were astonished when the EIA study team informed them that this will be a small research reactor with nominal power of 5 MW. This indicates that previously, there was no sufficient communication with the public to inform them about the reality of the JRTR project. To assure the public that the project is concerned with a research reactor, a visit to the project site was organized for representatives of the local communities from all the towns in the vicinity of the project site. The participants in the visit were allowed to tour the site, after which JAEC commissioners presented the objectives and benefits of the JRTR project. To enhance the public confidence, a visit of public representatives to JAEC headquarter was organized. During the visit, the relationship between JAEC and communities surrounding the JRTR site and means of improving such a relationship were discussed. It was agreed at the meeting to arrange a visit for public representatives to similar research reactors in operation outside Jordan. Due to different reasons, unfortunately such a visit was not accomplished.

To fulfill the EIA requirements, QRACEST has conducted a scoping and public hearing session which was attended by representatives of all project stakeholders. The main objective of the session is to ensure that all environmental issues of the JRTR project will be adequately addressed during all stages of the JRTR project life cycle.

At the beginning of the scoping session, the EIA consultant presented the EIA study objectives, scope of the study and issues to be covered. Then the participants were asked to identify any anticipated additional impacts during different phases (i.e. construction, operation and decommissioning) of the project which were not covered during the consultant presentation. This has resulted in enhancement of information and data collected earlier.

Finally, the project proponent was given the opportunity to elaborate on the project investment plan and capacity building plan of the local Jordanian nuclear engineers and scientists. This has led to beneficial exchange of ideas and information between the various stakeholders, Consulting team and the proponent.

As with all public hearing sessions, many of the stakeholders raised very important issues with respect to environmental and public health issues. Such issues were documented and will be considered in the EIA study.

5. Conclusions and Recommendations

The public opposition to nuclear energy projects has been widened after the Fukushima accident. The opposition is clearer in new comer states like Jordan. The issue is further complicated by the fact that the Jordanian regulatory frame work is lacking a well identified mechanism for public involvement in decision making regarding the siting of complex projects like nuclear facilities. Although came in a later stage, JUST involvement in the EIA study of JRTR has led to improved engagement and involvement of the public in the process of developing nuclear facilities in the country.

Some steps in the direction of stakeholder's involvement had to be taken before the site selection and starting the construction works. It is of great importance to understand why the public objects to nuclear facilities, so as to help addressing these objections in a more informed and strategic manner.

Figure 2. Steps of conducting EIA study in Jordan

REFERENCES

1. Polic M., Koc C., Zelezink N. (2012) Review of Public Participation in Radioactive Waste Siting Process in Slovinia, University of Ljubbljana, Slovinia.

2. IAEA Nuclear Energy Series, Technical Report No. NP-T-5.1, Specific Considerations and Milestones for a Research Reactor Project, Vienna, 2012

3. Richardson P., Rickwood K. and Rickwood P. (2012) Public Involvement As A Tool to Enhance Nuclear Safety, Energy Strategy Reviews, http://dx.doi.org/10.1016/j.esr.2012.11.002

4. Srinivasan T.N. and Rethinaraj T. S. (2013) Fukishima and Thereafter: Reassessment of Risks of Nuclear Power, Energy Policy, 52 pp 726-736.

5. Bryan L. W. and Melina S.M. (2007) Perception Towards Stewardship Among Residents Living Near U.S. Department of Energy Nuclear Facilities, Environmental Development and Sustainability. Vol. 9, pp 49-78.

6. Jordan Department of Statistics Bulitten, 2012, Amman Jordan

7. Jordan Atomic Energy Commission (JAEC) White Paper on Nuclear Energy in Jordan, Prepared by Worley Parsons, September, 2011.

CONCEPTUAL NUCLEAR DESIGN OF THE KIJANG RESEARCH REACTOR

C.G. SEO, H.T. CHAE, B.C. LEE, B.J. JUN, and I.C. LIM
Reactor Core Design Division
Korea Atomic Energy Research Institute, 150 Deokjin-dong Yuseong, Deajeon, 305-353–Korea

ABSTRACT

The Korea Atomic Energy Research Institute (KAERI) has finished a conceptual design of the KIJANG Research Reactor (KJRR), which will be located at KIJANG in the south-eastern province of Korea. The KJRR is a medium flux reactor of 15 MW power and loaded with the MTR (Materials Testing Reactor) type fuel assemblies, which use U-7Mo dispersion fuel with a uranium density of 8.0 gU/cm^3 as a reference fuel. The KJRR will be mainly utilized for isotope production, NTD (Neutron Transmutation Doping) production, and the related research activities. This paper presents the unique nuclear design concepts and nuclear characteristics of the KJRR.

1. Introduction

Since its first criticality in 1995, the HANARO research reactor has been operated successfully and the number of users and utilizations has been increased rapidly. It is expected that the demand for its utilization will exceed the capability of HANARO in the near future. We have been prepared in advance for the future demand and improved the experiences obtained from the design to operation stages of HANARO [1]. Based on the HANARO experiences, a conceptual core of an Advanced HANARO Reactor (AHR) was developed in 2006 [2]. The AHR core selected U_3Si_2 fuel of 4.0 gU/cm^3 as a reference fuel and can accommodate up to 6.0 gU/cm^3 U-Mo fuels. As higher uranium density fuels are being developed and MTR type fuel is more popular, we have also considered core concepts using MTR type fuel [3]. Recently, the Korean government decided to build a new research reactor of a MTR type fuel.
The new research reactor project was launched on the 1st of April, 2012. The reactor will be located at KiKANG in the south-eastern province of Korea, and the conceptual design has been finished. Various concepts for the reactor core and structure, as well as other systems, have been studied. This paper presents the conceptual core from the viewpoint of the reactor physics, which is described in section 2 in detail.

2. Nuclear Design

The KJRR will be mainly utilized for isotope production, NTD production, and the related research activities. The nuclear design should satisfy the basic design requirements, which are carefully prepared to fulfill its purpose. The requirements are as follows:

- Reactor power: ~20 MW
- Reactor type: pool type
- Max. thermal neutron flux: > 3.0×10^{14} n/cm^2s
- Operation day per year: ~ 300 days

- Reactor life: 50 years
- Fuel: LEU (Low Enriched Uranium) plate type fuel
- Reflector: Beryllium
- Coolant and flow direction in operation: H_2O, downward forced convection
- Reactor building: confinement

2.1 Core Concepts

The conceptual nuclear design of the KJRR satisfies all design requirements prepared, in which safety and economics were preferentially considered. The operation and maintenance were also considered important. In the design of the KJRR, several important concepts are employed as follows:

1) Core with edge trimmed irradiation hole: Usually a research reactor core has a core configuration with a constant fuel assembly pitch. The sizes of the in-core irradiation holes are limited to a multiple size of the fuel assembly. We developed a new design concept to overcome the constraint [4]. It was found that the concept is very useful and the KJRR core uses the new concept. The new concept is to construct a core using edge trimmed irradiation holes. A conceptual drawing of the irradiation hole is given in Fig. 1.

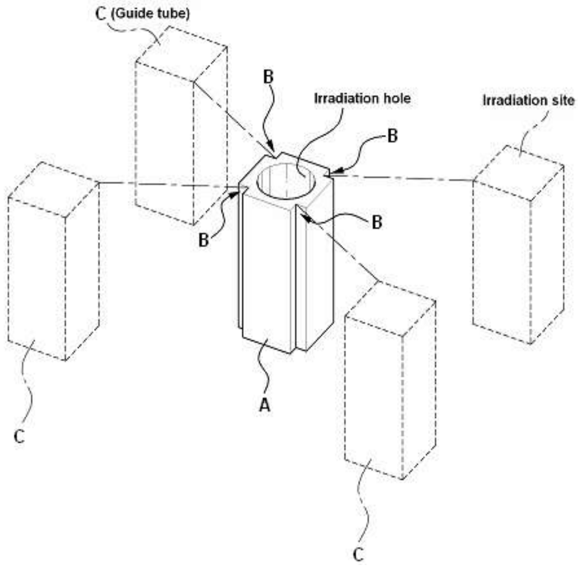

Fig. 1: Conceptual drawing of the edge trimmed irradiation hole

Edges of the irradiation hole are trimmed, unlike conventional irradiation holes which are rectangular boxes with a hole or holes. As the frame of the conventional irradiation hole is rectangular in shape, the space is not fully used for experimental facilities, which are of cylindrical shapes. The frame of the new irradiation hole becomes more compact by trimming superfluous parts. The four faces of the irradiation hole can be contacted with fuel assemblies, but the four corners of the irradiation hole should be in contact with other irradiation holes or guide tubes except the fuel assembly. The coolant in a fuel assembly flows at high speed, and therefore, the structural integrity of the fuel is important. Fuel should be placed by face-to-face contact with other structures such as a fuel assembly, irradiation hole, and guide tube of the control rod. Any corner of the core structures should not be in contact with the fuel plate or side plate of the fuel assembly. Other types of contacts with the irradiation hole are allowed to preferably maintain face-to-face contact with the fuel. This core concept provides a higher thermal flux and larger reactivity worth of the Control Absorber Rods (CARs).

2) U-Mo fuel: Higher fuel economy urges the use of high density fuel, the KJRR adopts U-7Mo fuel of 8.0 gU/cc as a reference fuel. As U-7Mo fuel of 8.0 gU/cc is not fully qualified, the success of the KJRR project is strongly dependent on the fuel qualification. To reduce the risk from the viewpoint of the nuclear design, the maximum burnup of the fuel is maintained to be below 90%U-235. The dimensions of the fuel assembly and the fuel plate were chosen as the standard size, in which the box size of the fuel assembly is 76.2 x 76.2 mm and the meat thickness of fuel plate is 0.51 mm. Each fuel assembly consists of 21 fuel plates. KAERI produces only the HANARO fuel of rod type, but we will supply the KJRR fuel from the initial core. At the start of the conceptual design, the fuel assembly was ready to use Cd wire as burnable poison, which is inserted into the side plates of a fuel assembly. Because a reactivity swing of the core is not so large, the fuel assembly does not contain any burnable poison for lower fuel price.

3) Detachable CARs: The KJRR core uses detachable CARs to control and shut down the reactor. Thus, the core is constructed using two types of fuel assemblies, a standard type and a follower type. The standard fuel and follower fuel have the same box size. When a follower fuel is loaded into the core, a Hf absorber is attached to the end of the fuel. As the fuel assembly and Hf absorber are moving together, a larger control rod worth is available to control the KJRR core with large uranium loading. Total uranium loading of the nominal core is 70.1 kgU.

4) Unique core configuration: The core configuration should be optimized according to its purpose. The core design is strongly dependent on the number of in-core irradiation holes and CARs. A core model with 3 in-core irradiation sites fully surrounded with fuel assemblies is selected as shown in Fig. 2. This core is composed of 7x9 lattices with its active length of 60 cm. The nominal core consists of 22 fuel assemblies, in which 16 standard and 6 follower fuel assemblies are loaded.

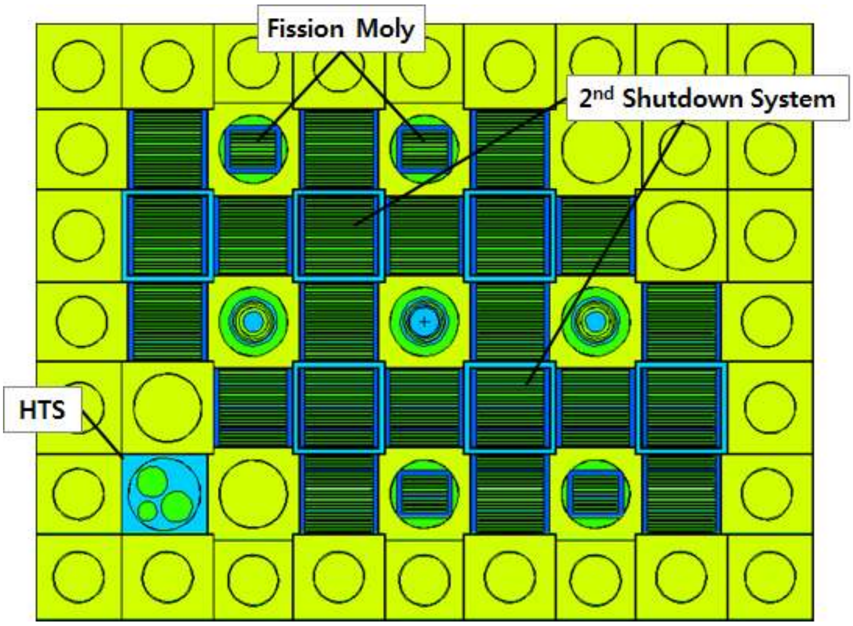

Fig. 2: A core configuration of the KJRR

The core has 6 CARs to control and shutdown the reactor. The reactor regulating system shares 4 CARs with the reactor protection system, which are driven by stepping motors. The independent secondary shutdown system uses 2 CARs, which are fully withdrawn at normal operation state by hydraulic force. The arrangement of the CARs is carefully studied to minimize the flux perturbation and maximize the reactivity worth. Figure 2 shows that 4 fission moly targets are loaded at the lateral positions, but more targets can be loaded. The core is located within a core box, which will prevent a core uncovered at any emergency state. A HTS (Hydraulic Transfer System) is located within the core box to get a thermal flux above 1.0×10^{14} n/cm^2/sec. Two PTS (Pheumatic Transfer System) and 5 NTD holes are located outside the core box. The outside of the core box surrounded with Be, Graphite and Al, is not fixed yet.

2.2 Nuclear Analysis

At the current design stage, nuclear analyses are mainly performed for an equilibrium cycle of a reference core. To confirm that the conceptual core satisfies the design performance and criteria, nuclear analyses were performed with two code systems. At the start of the conceptual design stage, we mainly used the coupled MCNP/HELIOS system [5], which consists of two well-known nuclear codes, MCNP and HELIOS. The MCNP code was used to evaluate the nuclear characteristics of the core, which uses continuous energy library based on ENDF/B-VII. The HELIOS code was used for supporting the burnup calculation in the system. Now, the McCARD code, which is a Monte Carlo (MC) neutron-photon transport simulation code designed exclusively for neutronics analyses of various nuclear reactor and fuel systems, is mainly used to confirm the results and get more detailed information for its burnt core. McCARD is capable of the burnup analysis using the built-in depletion equation solver module. Unlike many existing MC burnup analysis codes, it is not necessary to couple the MC neutronics analysis modules with an external depletion code. We use selectively one of two code systems according to its situation, but the basic data library is the same.

An equilibrium core is dependent on an operation strategy, so there may be various equilibrium cores according to a reactor operating strategy. Two fuel assemblies are loaded for one cycle operation considering a discharge burnup, a cycle length and an excess reactivity at a BOC (Begin Of Cycle) and an EOC (End Of Cycle). As there are many loading patterns, a sophisticated study is required. A loading pattern is selected to satisfy all design requirements at the same time. As a loading pattern is determined, a fresh core converges to an equilibrium core by repeated core calculations. For the selected equilibrium core, the cycle length was estimated as 50 days long. Without any burnable poison, the reactivity swing is only 63 mk. The equilibrium xenon load is estimated to be about 30 mk. The reactivity loss per day is estimated to be about 0.67 mk/day. The KJRR core is not a high flux reactor, about 12 mk makes us override xenon poisoning for about 1 hour. The excess reactivity is dependent on its target loading and the reactivity at a BOC was 75 mk at its nominal core with the required targets loaded. If the core reactivity at a BOC is 90 mk with most of targets unloaded, the minimum shutdown margin of the reactor protection system is over 35 mk and the second shutdown margin is about 40 mk.

The maximum thermal neutron flux ($E_n \leq 0.625$ eV) at the central flux trap is over 3.0×10^{14} n/cm^2/sec. The power of a fission moly target is below 100 kW per target. The neutron fluxes satisfy its design requirements. The assembly average discharge burnup is 67.0% of the initial U-235 loading and its local peak burnup is about 86%U-235. To evaluate the power peaking factors, all fuel plates were axially divided into 6 cm each. Peak power was evaluated for all possible control rod positions because it is sensitive to a control rod's position. The maximum power occurred at a BOC core with CARs 50% inserted and the maximum total peaking factor Fq is estimated as 2.40. Both the isothermal temperature coefficient and the power coefficient were negative, and thus the KJRR core is characterized as being inherently safe.

3. Concluding Remarks

Based on the experiences of HANARO's construction and operation, we succeeded in obtaining a conceptual core fulfilling its design requirements. This conceptual core provides a proper thermal flux at 15 MW power. The high discharge burnup will provide us with a high economic benefit. The U-Mo cores are favorable for a longer cycle core. The core design is based on internationally proven technology. As we adopt a high density fuel for KJRR, we should qualify the 8.0 gU/cm^3 U7Mo fuel. The main parameters of the KJRR core at the conceptual design state are summarized in table 1. The KJRR project is already at the basic design stage and more detailed results will arise.

References

[1] C. Park, “Design Approach to the Development of an Advanced HANARO Research Reactor”, Proc. of Int. Sym. HANARO 2005, Deajeon, Korea, 2005.

[2] C.G. Seo, et al., “Conceptual Neutronic Design of an Advanced HANARO Reactor Using the U_3Si_2 and U-Mo Fuel”, RERTR 6, Cape Town, South Africa, 2006.

[3] C.G. Seo, et al., “Conceptual Nuclear Design of a 10 MW Research Reactor with MTR type Fuel Assemblies”, Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 29-30, 2009.

[4] Chul Gyo Seo and Nam Zin Cho, "A Core Design Concept for Multi-purpose Research Reactors,” Nuclear Engineering and Design **252** (2012) 34-41, 2012.

[5] C.G. Seo, et al., "MCNP/HELIOS System for the HANARO Research Reactor Using the Table Lookup Method,” RRFM2003, Aix-en-Provence, France, March 9-12, 2003.

[6] H. J. Shim, B. S. Han, J. S. Jung, H. J. Park, and C. H. Kim, “McCARD: Monte Carlo Code for Advanced Reactor Design and Analysis,” Nuclear Engineering and Technology **44**, p161, 2012.

Table 1: Main parameters of the KJRR

Reactor		
	Type	open pool
	Power	15 MW
Core		
	Coolant	H2O
	Reflector	Be
	Core lattice	7x9
	Fuel type	MTR
	Number of fuel assembly	
	- Standard fuel	16
	- Follower fuel	6
	Control rod	
	- Material	Hf
	- Reactor regulating system	4
	- Second shutdown system	2
	Total uranium loading	70.1 kg
	Cycle length	50 days
	Number of fuel assembly/cycle	2
	Fuel consumption/year	12
Fuel		
	Active fuel length	600 mm
	Fuel box size	76.2×76.2 mm
	Thickness of fuel meat	0.51 mm
	Width of fuel meat	62.0 mm
	Thickness of fuel cladding	0.38 mm
	Fuel material	U-7Mo
	Fuel density	8.0 gU/cm^3
Reactivity		
	Reactivity swing	63 mk
	Xenon worth	30 mk
	Reactivity loss per day	0.67 mk
	Xenon over-ride for 1 hour	12 mk
	Shutdown margin (single failure)	35 mk
	Shutdown margin of 2nd system	40 mk
	Total worth of control rods	257 mk
Thermal/hydraulic design at normal operation		
	Core flow velocity	6.0 m/sec
	Inlet pressure, core coolant	0.18 MPa
	Inlet temperature, core coolant	35 ℃
	Average heat flux	415 kW/m^2
	Max. fuel temperature	142.3 ℃
	ONB (Onset of Nucleated Boiling) margin	10.0 ℃

IAEA PUBLICATION ON GOOD PRACTICES IN THE DEVELOPMENT OF THE TECHNICAL REQUIREMENTS FOR THE BIDDING PROCESS OF A NEW RESEARCH REACTOR

Y. BARNEA, A. BORIO di TIGLIOLE, P. ADELFANG

Research Reactors Section, NEFW, IAEA.
VIC, PO Box 100, Vienna, Austria

T. HARGITAI, H. ABOU-YEHIA, A.M.A. SHOKR,

Research Reactors Safety Section, NSNI, IAEA
VIC, PO Box 100, Vienna, Austria

ABSTRACT

More than 20 countries are currently in different stages of new research reactor projects. The majority of these Member States are building their first research reactor in preparation for embarking on a nuclear power programme. The IAEA recent activities on supporting these projects showed the need in the majority of these countries for guidance on the development of the bidding process. In responding to this need, the IAEA has finalized the development of a publication on the good practices on the development of the technical requirements for the bidding process for a research reactor project. The publication is to be used in conjunction with the other IAEA publications on research reactor safety and utilization and the supporting IAEA Safety Standards. The scope of this publication covers the bidding process from the preparation of the technical part of the bid specifications until the selection of the research reactor design and the signature of the contract, including criteria for bid evaluation. The guidance provided in the publication is primarily oriented to countries developing its first research reactor; however, such guidance could be also used for the bidding process of a subsequent reactor in a country. The publication is mainly directed to the turnkey contractual approach, but it is also useful in other kinds of contractual approaches. This paper presents an overview of the main technical contents of the IAEA publication and discusses the activities in supporting its Member States for its effective application.

1. INTRODUCTION

Many Member States (MS) have informed the IAEA of their interest in constructing a Research Reactor (RR), as their first major nuclear investment and opportunity to benefit from the peaceful uses of nuclear technology. These future RRs may have various roles, such as: a) building expertise for a nuclear power programme; b) providing services for society; c) serving as a major facility for education and training, and d) promoting science, technology and medical purposes. In responding to this trend, the IAEA published last year a document on the Milestones for a new RR project [1]. The document emphasizes that some fundamental circumstances must be considered before embarking on a new project: a) the RR project will create long term obligations for the safe operation of the reactor and proper management of the associated spent fuel and radioactive waste; b) These new projects are set in a context where currently almost half of the world's existing RRs are underutilized, facing budgetary resource challenges, that may affect their operational condition. This present paper aim is to review a recent IAEA technical guidance document, addressed to MS new to nuclear technologies that covers the bidding process from the preparation of the **Bid Invitation Specification (BIS)** until the selection of the RR design and the signature of the contract with the contractor [2]. As so, the new document is to be used to bridge the gap between the feasibility studies (Milestone 1) and bid specification (Milestone 2), as depicted in the Annex as Fig. 1, initial presented in the Milestones document [1]. The guidance applies to all reactor types and technologies, and as so is not recommending a specific reactor type or technology or a specific design. However, it is assumed that the recent document will be used by a MS that has already decided that general features as: *easy-care, endurable and safe* RR is appropriate to be considered the country's needs, as it establishes its first nuclear installation.

STRUCTURE OF THE DOCUMENT [2]

The recent IAEA document [2] is structured as follows: Chapter 1 provides the background and the objectives; Chapter 2 discusses the general considerations, the description and preconditions of the bidding process, the entities involved and their responsibilities, as well as additional aspects such as schedule of the process and pre-qualifications of the bidders. Chapter 3 provides a detailed description of the general considerations for developing a BIS, such as site selection and specification, fuel supply and bid evaluation criteria. Chapter 4 addresses RR utilization related design features and Chapter 5 provides description of the fundamental specific design requirements that should be included in the BIS. Special emphasizes is given to the IAEA safety requirements and safety demonstration requirements to be included. Chapter 6 describes and recommend the organizational structure to be implemented by the future owner and operator of a RR. Moreover, the chapter refers to the training needed by newly recruited or existing local professional staff. Through Chapter 7, the reader is offered a comprehensive guidance on the list of documents, technical data and specific technical assistance that the vendor must provide, in order to define properly the MS management systems. In Chapter 8, the reader is introduced to a list of infrastructure related facilities that have to be specified by the owner and operator and supplied by the vendor to build, operate and safely utilize the new RR. Finally, Chapter 9 includes the listing the references from IAEA previous publications. The present paper is limited only to the review the BIS as described in Chapters 3 and 5 of the recent IAEA publication.

2. GENERAL CONSIDERATIONS IN DEVELOPING BIS

PRECONDITIONS

The decision to build a RR is based on the results of previously performed activities like feasibility studies showing the justification for the need of a RR, siting studies, development of a strategic plan and establishing a regulatory infrastructure. Moreover, it is assumed that Phase 1 allows the future operator to gather a consortium of stakeholders to ensure long-term financial support for the safe and good operation of the RR [1]. In these activities the advisability of acquiring the RR and the principal characteristics of the reactor project are investigated and the results constitute the background of the project. At the end of the preparatory activities, the owner/operator should be able to start the BIS process. The following topics have to be understood, decided and agreed prior the commencement of the bidding process:

- Adherence of international conventions and treaties;
- Regulatory requirements and licensing;
- Reactor size (or size range);
- General technical requirements;
- Site characteristics and preliminary environmental impact assessment;
- Management systems of the owner;
- Financing resources (including the national funding option);
- Utilization plan;
- Nuclear fuel supply options;
- Nuclear waste management/disposal;
- Radiation protection and emergency planning;
- Safeguard features;
- Strategy for human resources development.
- Previous experiences of potential contractors;
- Overall project schedule, contractual approach and project management;

HUMAN RESOURCES

During the pre-project phase [1] it is strongly recommended to develop the following human resources: a) technical expertise to develop specifications for the RR and to evaluate the bids taking into account constructability and commissioning, operability and maintainability, safety and licensing, utilization, fuel cycle, radioactive waste management and decommissioning, safeguards, security and emergency planning; b) project management expertise to manage the bidding process, to develop specifications and to evaluate the bids; c) existing knowledge of the country's and of the site's infrastructure (such as geological survey capability, services infrastructure, etc.) as well as the international best practices including IAEA Safety Standards and the regulatory requirements, often necessary to be established or upgraded and expedited during the bidding process; d) legal and financial expertise for BIS preparation, bid evaluation, contract negotiations and fuel procurement and e) expertise in communication and public information.

FUEL SUPPLY

The nuclear fuel may be offered either as part of the bid for the RR or via a separate contract. In all cases, the provision of fuel should be included in the scope of supply. The Operating Organization (OO) must describe in the BIS his programme regarding the fuel cycle activities (back end). This programme should be in compliance with the international treaties and obligations on safeguards of nuclear material and agreements with the fuel supplier, considering: the safety and security of supply; safety and security of fuel transport; new and spent fuel storage; reprocessing (as applicable) and waste management. The OO may like to obtain offers for additional fuel supply through competitive bids from qualified manufacturers. Therefore it may request the bidders to express their commitment to deliver within their scope of supply all relevant data on the fuel, including information on the physical, thermal-hydraulic, thermodynamic and mechanical properties and calculations, as well as calculations of fuel management and refuelling requirements. It is recommended that the compatibility and interfaces between all project partners are carefully evaluated and contractually well defined, with IAEA assistance as necessary.

3. BIS SPECIFIC DESIGN REQUIREMENTS

TECHNICAL REQUIREMENTS

The first stage of the bidding process is the preparation of technical requirements for the bidding process. A pioneer RR in a MS new to nuclear technology is assumed, inter alia, to have the following features:

a) By robust design can endure operator's errors without core damage.
b) Is user (operator/experimentalist) friendly.
c) Easy to operate, inspect and maintain.
d) Allows unlimited time of safe access to the rector hall during the operation on full power.
e) Has a well-defined long term fuel management ("back end") programme.

The general requirements from such a RR have to satisfy the safety objectives, with emphasises on radiation protection, such as:

- Adequacy to the defence in depth concept.
- The core and the coolant may not operate at high pressure.
- The overall reactivity feed back coefficient (considering the fuel and moderator temperature, density and void coefficient and coolant temperature) shoul be proofed and experimental verified negative, through the all operating stages.
- The reactor has to include inherent safety features as well as passive systems (e.g., natural circulation for residual heat removing and normally-open gravitation based systems).

- Radiation levels during operation should be minimised by the As Low As Reasonable Acheivable optimization method, and the radiation level in the reactor hall have to be below national authority requirements, to allow workers and users to safe access the hall during reactor operation.
- The human machine interface should be based on proven, state–of–the-art technologies and proofed as user-friendly.
- Safety systems have to be self-actuated. As so, operator actions should not be required for an initial specified time, following a postulated initiating event.
- Testing of the safety systems have to be possible even when the reactor is functioning at nominal power without causing a spurious shutdown.
- The safety systems must have high availability and reliability based on concepts of redundancy, diversity, physical separation, protection against single and common mode failures, etc.
- The reactor design has to withstand, without any prompt intervention, credible combinations of external events, typical of its environment.
- The reactor design must avoid vulnerabilities of the critical safety functions, following an external or internal accidental event (i.e. fire).
- Reffueling in the core configuration should not be frequently required and have to be simple to be carried out. A reasonable size of on-site spent fuel storage has to be able to provide space for at least two cores volume.
- Radioactive waste generation should be minimised by means of the design and procedures.
- The safety features of the reactor must help in gaining public acceptance, and the simplicity of the design must aid public understanding of the likelihood of systems failures

MAIN SAFETY FEATURES OF THE DESIGN

Regarding the safety requirements for the reactor core design the BIS must refer to the following:

- The overall reactivity feedback coefficient should be proofed negative through all operation stages and conditions. The overall reactivity feedback coefficient should be measurable and the verification should be included in the commissioning program;
- Adequate shutdown margin should be ensured in all operational states, including the case of a single failure of the highest reactivity worth control rod;
- Limitation of the maximum excess reactivity of the core;
- Limitation of the reactivity worth that might be inserted by a single action, e.g., experiments, operator action or single failure;
- Limitation of rate of positive reactivity addition allowed by the reactivity control system; and
- Limitation of the reactivity worth of experiments (fixed and non-fixed).
- The safety system settings should be established with such a margin between the initiation point and the safety limits that the action initiated by the protection system will be able to control the process before the safety limit is reached, in compliance with the safety analysis results. Some of the factors in establishing this margin are: a) inaccuracy of the instrumentation; b) uncertainty in calibration; c) instrument drift; and d) instrument and system response time.
- Passive decay heat removal from the fuel should be sufficient to prevent fuel damage, i.e. no fuel melting and no significant degradation of fuel containment capability. In case of a pool type RRs, the water inventory of the pool should be enough to accommodate the decay energy without external cooling (this requirement limits power and power density).
- It should be demonstrated in the design that the reactivity control system will function properly under all operational states of the reactor and will maintain its reactor shutdown capability under all DBA conditions also, including failures of the control system itself.
- At least one automatic shutdown system should be incorporated into the design.
- No single failure in the shutdown system should prevent the system from fulfilling its safety function when required (e.g. with the most reactive shutdown rod stuck in the out position).

DESIGN LIMITS

Design limits of the reactor should be established on variables that can be directly measured in all operational states or on variables that can be readily related to a measurable quantity. These variables may include: neutron flux, neutron flux rate (reactor period), thermal power, fuel temperature, pressure drop across the core, inlet and outlet core coolant temperature, coolant level in the reactor pool, coolant flow rate in the reactor core, control rod position, etc.
Design limits for core cooling should be defined in order to prevent the occurrence of thermal-hydraulic critical phenomena such as departure from nucleate boiling and flow instability, during steady state and transient operating conditions. These phenomena can lead to coolant boiling on the surface of the fuel cladding assembly, which may cause cladding failure, leading to radioactivity release into coolant and to its further escape outside the cooling circuit.

PROTECTION SYSTEM FEATURES

The reactor protection system should be capable of automatically initiating the required protective actions for the full range of design basis occurrences to terminate the sequence of events safely. This capability has to take into account the possible malfunction of parts of the system, i.e. single failures. The reactor protection system should be designed in such a way that:

- Protective actions are initiated automatically;
- Once initiated, the protective actions should proceed to completion and cannot be impaired or prevented by manual actions;
- Manual actions will not be necessary within a certain period of time following an incident;
- Manual reactor trip signals should be provided as an input of the system and consideration should be given to the provision of the capability to initiate reactor shutdown from a remote location;
- All components of the protection system should be capable of being functionally tested.

CONCEPTUAL SAFETY ASSESSMENT

The main deliverable related to safety during the design phase will be the Preliminary Safety Analysis Report (PSAR) prepared by the vendor based on the safety oriented description and safety assessment of the facility [3].The PSAR is not part of the bid. Nevertheless, at the bid stage, a conceptual safety assessment should be prepared by the vendor to demonstrate compliance with safety acceptance criteria and objectives. The generic process for the safety analysis is described in IAEA publications [3], [4]. The main approach for the safety demonstration has to follow deterministic methods, though probabilistic methods can be used as complementary tool. For deterministic methods, the approach defining accidental sequences and emergency planning must be defined. For probabilistic methods, the risk integrates the likelihood and the severity of each of the consequences. A safety assessment is an integral component of the design process and has to be carried out following standard practices [4]. It provides a feedback mechanism to the designers for verification that the proposed design solutions comply with safety acceptance criteria. Therefore, some preliminary assessment of the safety of the facility must be part of the documentation required from the vendor during the bidding process. The process of safety assessment is presented in the Annex (Figure 2) as a summary diagram.

FLEXIBILITY IN OPERATION AND MAINTENANCE (EASY CARE)

The "easy care" distinctive features of the design refer mainly to the followings (additional detailed requirements are provided in IAEA Safety Standards [5] and [6]) and include, among others:

- User (operator/experimentalists)-friendly, flexible and easy to maintain;
- Provision of extended period between physical inspections or maintenance of reactor systems;
- Reduction of the need for local human actions through the use of automated systems;
- Refuelling the core is not frequently required and can be easily carried out;

- Radiation levels during operation are minimised, and the radiation level in the reactor hall is low enough to allow workers and users to access the hall during reactor operation;
- Human machine interface is based on proven, state-of-the-art technology and demonstrated to be user-friendly;
- Design features to ease maintenance are included, such as provision to store coolant during pool maintenance activities.

The design should provide easy access to the reactor core and to the experiments. The demands on the operator should be minimized by the design so as to reduce the burden on the operator and bound human error by adopting clear displays, audible signals and automated safety actions.

REQUIREMENTS FOR THE VENDOR

The following topics have to be addressed and the information must be provided by the vendor: a) Information on the implementation of measures of defence in depth [7], in order to identify and implement prevention and mitigation measures for all postulated initiating events in the design of the facility. The mitigation measures must be actuated by engineered safety features or on-site procedures established by the operator; b) A description of the methodology used for the safety classification of Systems Structure and Components (SSCs). This information has to include: the number and description of safety categories or classes adopted and the requirements on the design, quality assurance (QA), time of performance, time between maintenance requirements for SSCs in each safety category; c) A preliminary list of acceptance criteria for all SSCs performing a safety function, such as actuation time, acceptable delays and negativity reactivity worth inserted by shutdown system, and the means used to demonstrate that the acceptance criteria are met by the design, in each operational and accident state; d) A list of all the codes and standards that will be used in the design and construction of the reactor. This list must contain mandatory national standards and international standards, including IAEA Safety Standards. This list must remain contingent to the acceptance of the OO and the regulatory authority. In the absence of such codes and standards, the results of experience, tests, analyses or a combination of these may be applied, and this results based approach have to be justified; e) All necessary information on the computational tools that are used in the safety analyses of the facility; f) Information on previous experience with the code and all the work that has been done previously to demonstrate that the software is applicable to calculate the conditions of the reactor; g) The information for the applicability of all correlations, equations, approximations and models to the range of conditions analysed with the software, including all information pertinent to the verification of the code.

4. BID EVALUATION CRITERIA

The bidding process is divided in several main phases: a) preparation of the BIS (by the (OO); b) preparation of bids (by bidders); c) evaluation of bids (by the OO); d) contract negotiations (by the OO and selected bidders); e) signature of the contract (by the OO and contractor). The evaluation criteria may include the following items:

- Compliance of the bid with the contents and requirements of the BIS. Compliance with the terms and conditions of the draft contract, completeness of supply;
- Experience, reputation, organization, facilities, services and financial resources of the bidder;
- Project structure, project organization and implementation plan of the bidder;
- Safety features of the design;
- Compliance of the bid with the IAEA Safety Standards;
- Technical characteristics of the RR, status and provenness of design, standardization, constructability, operability, useability, inspectabilty and maintainability of the facility;
- Project schedule;
- Quality management practices, procedures and measures;

- Assurance of fuel supply and fuel cycle services;
- Assurance of nuclear safety, demonstrated licenseability of the facility, environmental effects, waste management;
- Type and contents of documentation provided;
- Flexibility of the operation and ease of maintenance;
- National participation (local contractors and suppliers) and technology transfer, training programme;
- Quality and extent of follow-up services of the bidder during the facility operation;
- Prices, price adjustments, foreign and local currency requirements;
- Terms of payment and financing conditions;
- Assurance of supply of the facility and spare parts, including heavy water, if applicable;
- Warranties.

In addition, the OO should identify the reasons (fatal flaws) based upon which the OO is entitled to eliminate the bid from evaluation process.

5. CONCLUSIONS

The publication reviews an IAEA recent publication to consider the technical requirements to be utilized, by the MS new to nuclear technologies, in the bidding process of a first RR project. The guidance provided applies to all reactor types and technologies, so this publication therefore is not recommending a specific reactor type or technology or a specific design. The document is mainly directed to the turnkey contractual approach, but it may also be useful in other kinds of contractual frameworks. It assumes that the necessary preparatory work has been completed before entering the bidding process and therefore, financial aspects of the bidding process are beyond the scope of this publication. It is notable that, although the intent is to develop the technical requirements of the bidding process for the first RR in the country, many ideas in guidance are also suitable for countries building a subsequent RR.

6. REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Specific Consideration and Milestones for a Research Reactor Project, Nuclear Energy Series No. NP-T-5.1, IAEA, Vienna (2012).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Good Practices to Develop Technical Requirements for the Bidding Process of a New Research Reactor, Nuclear Energy Series - in print, (2013).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment of Research Reactors and Preparation of the Safety Analysis Report, Safety Standards Series No. SSG-20, IAEA, Vienna (2012).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Analysis for Research Reactors Safety Reports Series No. 55, IAEA, Vienna (2008).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, Safety Standards Series No. NS-R-4, IAEA, Vienna (2005).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Periodic Testing and Inspection for RRs, Safety Standards Series No NS-G-4.2, IAEA, Vienna (2007).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Defence in Depth in Nuclear Safety, INSAG-10, IAEA, Vienna (1996).

ACKNOWLEDGEMENT

The following Research Reactors international experts were major contributors to the drafting and review process of the IAEA document [2]: G. Bignan (CEA), H. Bock (TUVA), R. Crone (ORNL), V. Garea (INVAP), G. Hampel (JGU-Mainz), I.C.Lim (KAERI), Y. Luzheng (CNNC), C. Pascal (AREVA-TA), A.L.Petelin (RIAR) and M.Villa (TUVA).The complete list of contributors is posted in the final publication and the IAEA acknowledges them all.

ANNEX

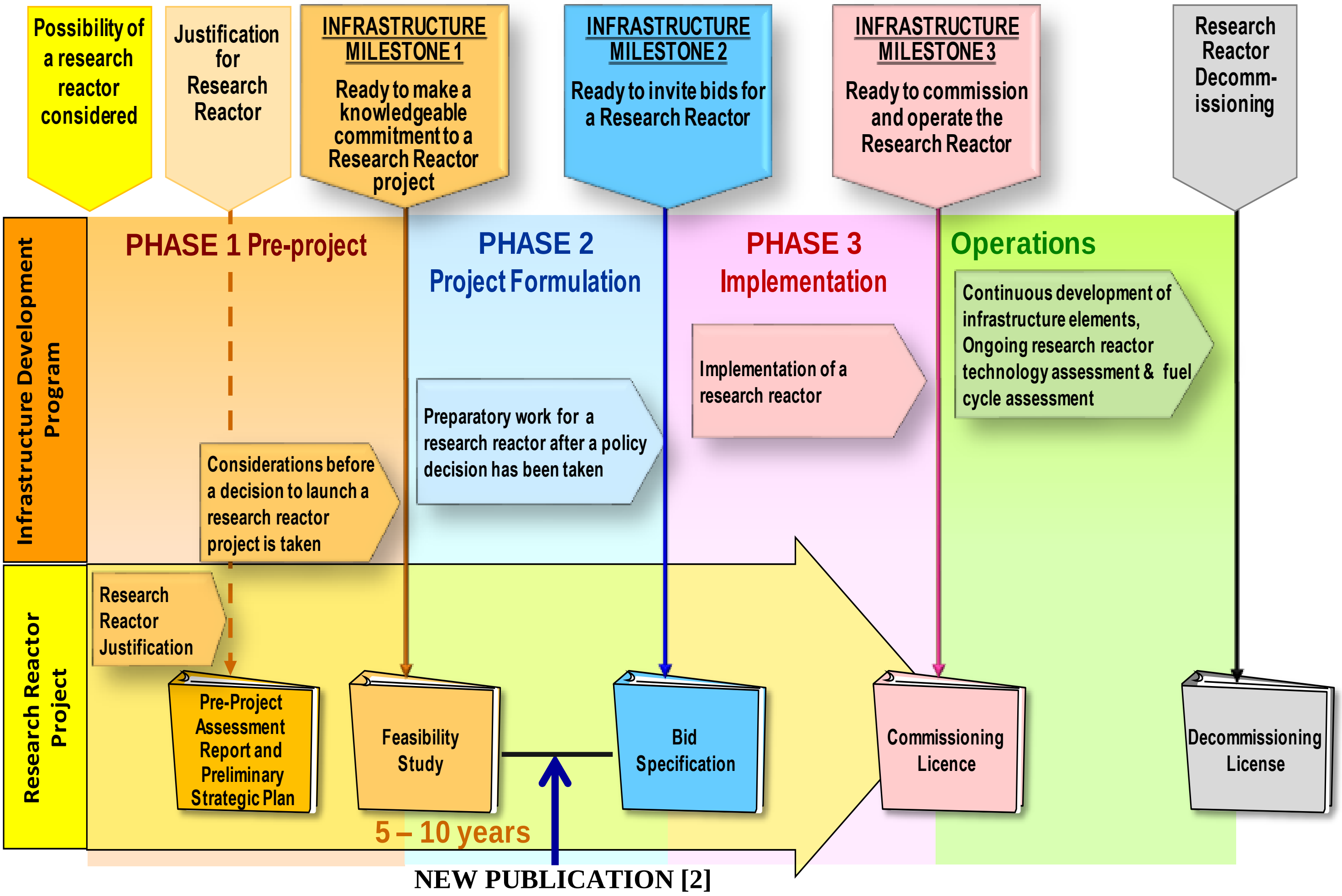

FIG 1: Indicating the present IAEA publication in the Milestones stages for a new RR project [1]

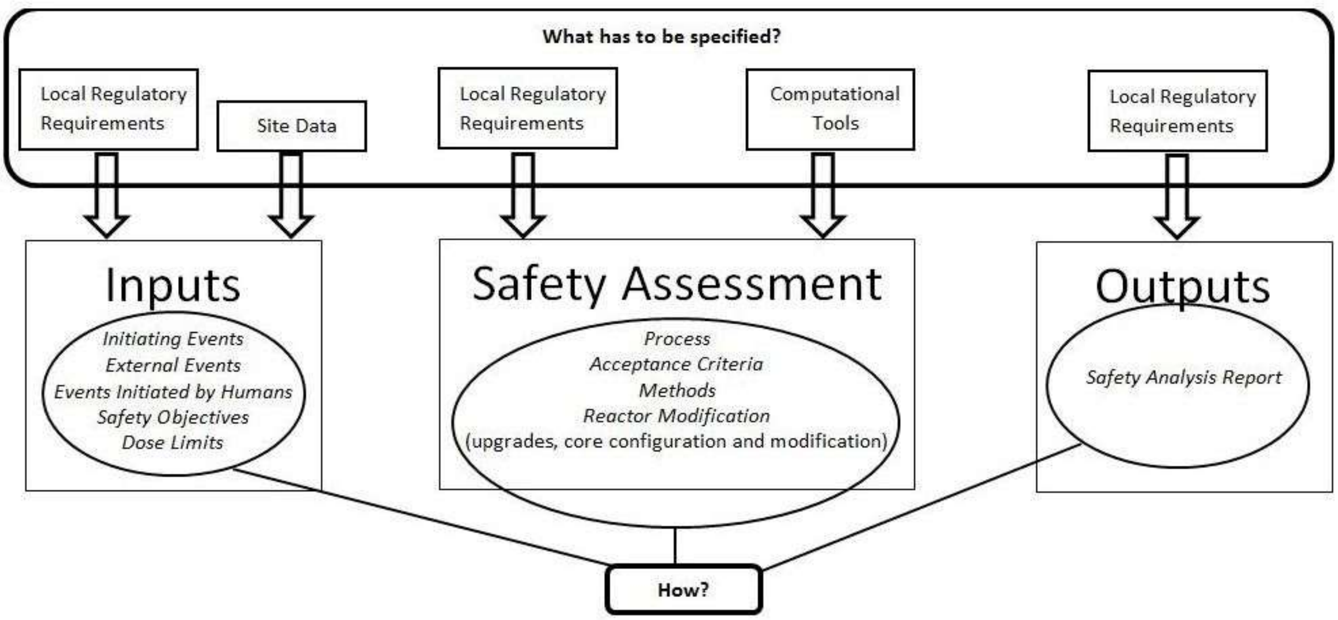

FIG. 2: Diagram of the proposed conceptual Safety Assessment process [2].

PROJECT DEVELOPMENT
FOR PROMISING POOL-TYPE RESEARCH REACTORS

I.T. TRETIYAKOV, S.A. SOKOLOV, V.I. TRUSHKIN, R.P. KUATBEKOV,
O.A. KRAVTSOVA, S.V. OSIPOVICH, K.A. NIKEL, A.V. GORYACHIKH

Joint-Stock Company "N.A. Dollezhal Research and Development Institute of Power Engineering" (JSC "NIKIET"),
2/8, Malaya Krasnoselskaya ul., 107140, Moscow, Russian Federation

1. Introduction

The beginning of this century saw significant abatement of the last century's global trend for a decrease in the number of operating research reactors as well as an emerging interest in new facilities shown, *inter alia*, by countries that have no nuclear infrastructure.

Admittedly, advancement of research reactors (RR) will not be as vigorous as it used to be in the 1960s, but they are still the cheapest and most readily available sources of high neutron fluxes and will therefore hold the interest of experimenters for many years to come.

Analysis of the current and projected uses of research reactors and assessment of the external market demands have prompted the power range of advanced research reactors. It comprises four RR versions designed to have competitive service parameters and to support a broad spectrum of studies in:

- nuclear physics,
- solid-state physics,
- radiation material science,
- neutron-activation analysis,
- neutron radiography of various products,
- silicon doping, production of medical and industrial isotopes (^{99}Mo, ^{131}I, ^{125}I, ^{35}S, ^{32}P, ^{90}Y, ^{166}Ho, ^{60}Co, ^{153}Sm, ^{192}Ir).

Research reactors can be used as training facilities and neutron sources for neutron therapy either.

The pool reactor has been reasonably selected given its long-term history of safe and effective operations. Pool reactors are both highly safe and ensure high thermal neutron fluxes which are sufficient for carrying out nearly all kinds of studies involving use of thermal neutrons.

In the past, research reactors normally operated on uranium enriched to more than 20 % (HEU), which is a real threat from the viewpoint of illicit proliferation of fissile material. All new research reactors are designed to run with commercially available and well-proven fuel of the low enrichment.

2. R&D purposes and areas

NIKIET pursues research and development in the following directions:

– participation in the activities to develop and produce competitive Russian LEU-fuel;

– preparation of technical proposals for design of future research reactors (100 kW to 20 MW in capacity) keyed to potential foreign demand.

2.1 Russian LEU fuel

Three types of fuel assemblies (FA) commercially available in Russia were chosen for the reactors, namely: VVR-M2 for the smaller research reactors and IRT-4M for the 10-20 MW reactors, as was also the newly developed VVR-KN fuel assembly for the latters. The general view of the fuel assemblies is given in Figures 1,3,6 and their technical characteristics are summarized in Table 1.

Parameter	VVR-M2	IRT-4M with 6/8 fuel elements	VVR-KN with 5/8 fuel elements
Fuel portion height, mm	600	600	600
Fuel material	UO_2-Al	UO_2-Al	UO_2-Al
Enrichment in ^{235}U, %	19.7	19.7	19.7
^{235}U content in fuel assembly, g	50	263.8/300	196/245
U concentration, g/cm^3	2.5	3	3
Fuel cladding	SAV-1	SAV-1	SAV-1
Structural material of end pieces	SAV-6	SAV-6 (AMg2)	SAV-6 (AMg2)
Reference reactors	DRR(Vietnam), BRR(Hungary), VVR-M Kiev (Ukraine)	IRT-1(Libya), IRT-Sofia (Bulgaria), VR-1, LVR-15(Czechia), VVR-CM Tashkent (Uzbekistan)	Production is launched in May, 2012

Tab.1: Technical characteristics of fuel assemblies made in Russia

The VVR-M2 fuel assemblies have successfully operated in Vietnam, Hungary and the Ukraine, and the IRT-4M assemblies have shown equally good performance in Bulgaria, Czechia and Libya.

Production of VVR-KN assembly was launched in May, 2012. The core for critical assembly WWR-K (in Kazakhstan) has been already configured with VVR-KN.

2.2 The power range of advanced research reactors

Analysis of the current and projected uses of research reactors and assessment of the external market demands prompted four design options of a pool-type reactor, namely:

- a small reactor (200 kW) with natural coolant circulation through its core;
- a small reactor (1MW) with forced coolant circulation;
- 10 MW multi-purpose reactor with forced coolant circulation;
- 20 MW high-flux reactor with forced coolant circulation.

3. Principles of designing advanced research reactors

Development of new research reactors in line with international rules should be guided by the following conceptual design provisions and principles of use at nuclear research centres.

3.1. Reliability:

- application of design approaches and components well-proven during reactor operation in Russia and abroad;
- choice of coolant flow rates and pressure drops in the core to provide the required boiling margin and heat engineering index.

3.2. Safety:

- core arrangement deep in a pool of water;
- the reactor designed to keep the core under water in the event of leaks in pipelines;
- leak monitoring, collection and return to the pool during accidents;
- no surface boiling at fuel elements and core components;
- adequate worth of control and protection system (CPS) rods;

- passive safety systems;
- negative reactivity feedbacks;
- presence of beryllium in the reflector to ensure safe reactor control during startup;
- use of reference IRT-4M and VVR-M2 fuel assemblies with LEU fuel;
- development of new VVR-KN assemblies with LEU fuel;
- handling operations under water.

3.3. Efficiency:

- high neutron flux in the reactor experimental devices;
- high burn-up of discharged fuel assemblies;
- high “reactor merit” (Φ/N);
- large variety of experimental positions.

3.4. Flexibility:

- reconfigurability of the reactor core;
- variability of the number and location of experimental channels.

4. RR technical characteristics

The core configurations offer optimal service characteristics (see Table 2). Versions of the reactor core maps are given in Figures 2,4,5,7,8.

5. RR construction features

Reactors suggested have much in common. In potential pool-type RR demineralized water is used as the coolant, moderator, axial reflector and radiation shielding material. Pool-type reactor is accommodated inside a concrete shield building and comprises a tank, which serves as the pool’s outer containment, a core, a beryllium reflector, the CPS actuators, ionization chamber channels, an upper shielding plate, horizontal hole gate valves and experimental devices. The reactor tank is also used for the interim storage of spent FAs. The reactor’s pool design makes it much easier for FAs and irradiated samples to be placed in and withdrawn from the core.

The reactors under design are intended for carrying out operations using experimental holes that can be inserted into the core cells, into the replaceable beryllium blocks, into the central trap and into the fixed reflector cells. It is not only ample experimental capabilities that is offered by vertical holes but also the capacity for generation of commercial isotopes and doped silicon.

For off-core neutron beam activities, including for medical purpose, the reactors will include 4 horizontal holes each.

Structurally, the reactor design permits the number of holes to be great enough. The list of the experimental facilities and devices for the reactor will be subject to update as the user desires.

Description of parameter	200 kW	1 MW	10 MW RR		20 MW RR	
FA type	VVR-M2	VVR-M2	IRT-4M	VVR-KN	IRT-4M	VVR-KN
Thermal power, MW	0.2	1	10	10	20	20
Number of FAs in core	70	70	16	26	40	45
Core height, m	600	600	600	600	600	600
Fuel enrichment in ^{235}U, %	19.7	19.7	19.7	19.7	19.7	19.7
Maximum thermal neutron flux (E<0.625 eV), $\times10^{14}$ $cm^{-2}\cdot s^{-1}$:						
in core	0.092	0.44	3.2	3.3	4.1	4.6
in beryllium reflector	0.02-0.04	0.2	2	2	1.4	1.2
Undisturbed neutron flux at the silicon doping channel (Ø 205 mm) location, $\times10^{13}$ $cm^{-2}\cdot s^{-1}$:						
thermal neutrons (E<0.625 eV)	-	-	3.8	3.7	6	9
fast neutrons (E>0.82 MeV)	-	-	0.03	0.03	0.03	0.1
Neutron flux at horizontal hole outlets, $\times10^{10}$ $cm^{-2}\cdot s^{-1}$:						
thermal neutrons (E<0.625 eV)	0.028	0.1-0.15	0.8-1.3	0.8-1.3	1.2-2	0.6-1.8
fast neutrons (E>0.82 MeV)	0.022	0.1-0.12	0.004-0.05	0.004-0.05	0.01-0.08	0.003-0.034
Undisturbed thermal neutron flux (E<0.625 eV) at hydraulic rabbit system locations, $\times10^{13}$ $cm^{-2}\cdot s^{-1}$:	0.34-0.4	0.02	0.2	0.2	0.4	1.2
Number of horizontal experimental holes	3	4	4	4	up to 5	up to 5
Number of vertical experimental holes	9	5	up to 25	up to 25	up to 20	up to 17
CPS actuator absorber	B_4C	B_4C	B_4C	B_4C	B_4C	B_4C
Number of control rods, including:	9	9	11	10	21	16
shim rods	6	6	8	6	18	12
automatic control rods	1	1	1	1	1	1
scram rods	2	2	2	3	2	3
Temperature effect, %ΔK/K	-0.08	-0.5	-0.3	-0.3	-0.2	-0.15
Average fuel burn-up in discharged FA, %	50	50	50	50	50	50
“Reactor merit” in thermal neutrons (Φ/N), $1/cm^2 s\cdot W$	$4.6\cdot10^7$	$4.4\cdot10^7$	$3.2\cdot10^7$	$3.3\cdot10^7$	$2.05\cdot10^7$	$2.3\cdot10^7$

Tab.2: Basic characteristics for 200 kW, 1, 10 and 20 MW research reactors

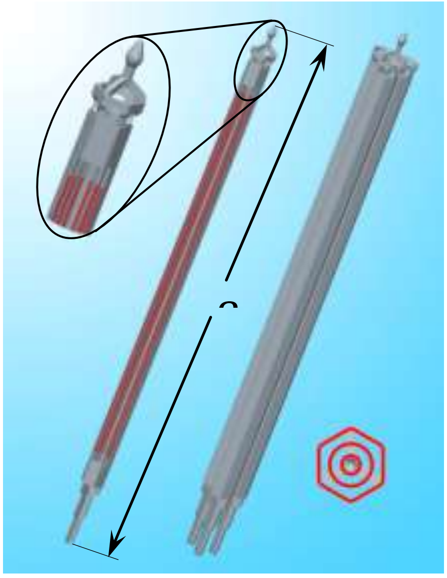

Fig. 1. VVR-M2

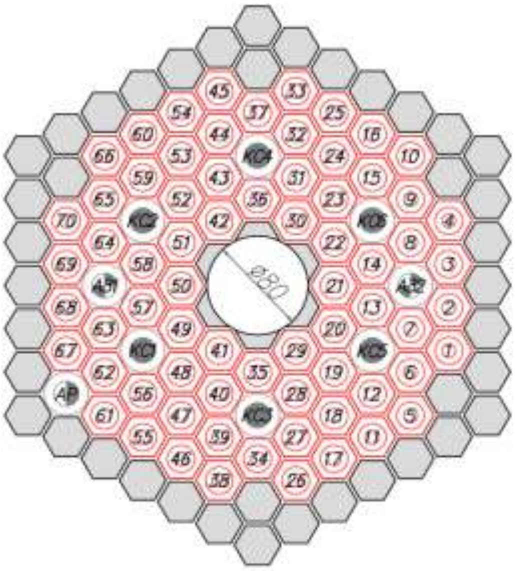

Fig. 2. Core map with VVR-M2
for small RR (up to 1 MW)

Fig. 3. VVR-KN

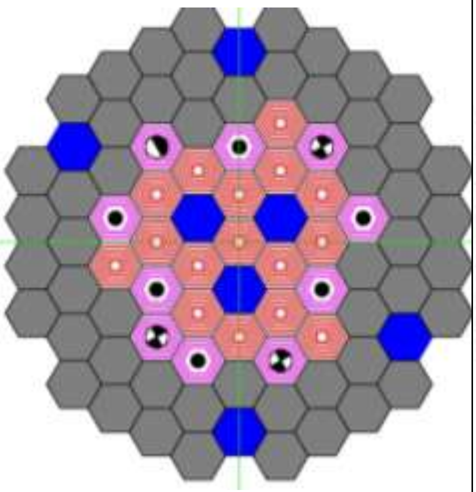

Fig. 4. Core map with VVR-KN
for 10 MW RR

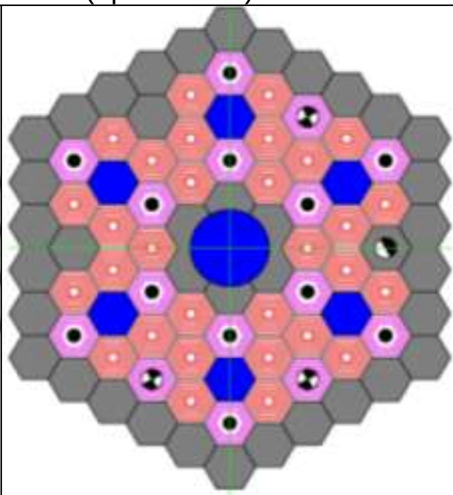

Fig. 5. Core map with VVR-KN
for 20 MW RR

Fig. 6. IRT-4M

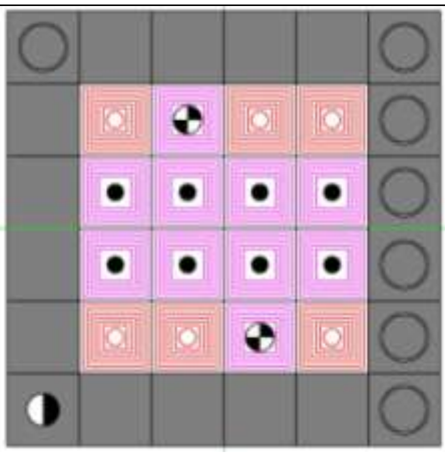

Fig. 7. Core map with IRT-4M
for 10 MW RR

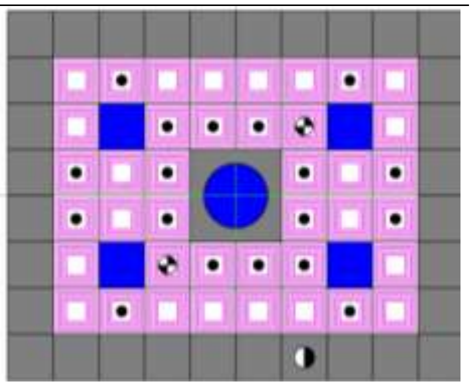

Fig. 8. Core map with IRT-4M
for 20 MW RR

6. R&D results achieved

The following engineering and design concepts were developed as part of the technical proposals for the reactor facilities with water-cooled water-moderated research reactors:
- circuitry designs,
- estimates of neutronic and thermal-hydraulic parameters,
- core and reflector layouts,
- core and reflector cooling systems,
- systems for handling of irradiated items,
- RF circuit diagrams,
- also the cost of the design documentation development, equipment fabrication and RF construction and commissioning support activities was determined.

Further activities had the purpose of creating RR designs as part of the nuclear research centres (NRC) to be assigned to a set of tasks defined with regard for specific user demands.

These materials formed the basis for the following herein-listed evolution phases of the NRC baseline designs:
- selection of components for experimental facilities and laboratories the NRC includes;
- determination of the composition and the scientific, production, engineering and infrastructural support for the isotope generation and production of doped silicon, and the materials research support;
- cost estimation for scientific, production, engineering and infrastructural support of the NRC in accordance with its designated function;
- NRC drafting.

Placing of buildings outlined on the construction site includes all basic and auxiliary structures, advanced infrastructure, branch line system and physical security.

7. Conclusion

NIKIET is ready to offer to those countries interested in the development of nuclear technologies RR designs meeting all international design standards for such facilities.

On the one hand, as typical designs, these are attractive in terms of the price and quality ratio. On the other hands, these designs give the potential customer a kind of a choice with respect to the NRC components depending on the RR application planned and the specific customer needs.

NIKIET contacts:
Tel. +7(499)263 73 88, +7(499)263 73 26, nikiet@nikiet.ru

European Nuclear Society
56, avenue des Arts
1000 Brussels, Belgium
Telephone: +32 2 505 30 50 - FAX: +32 2 502 39 02
rrfm2013@euronuclear.org
www.rrfm2013.org