Current Status of the KJRR Project and its Design Features

C.PARK, J.Y.KIM, H.T.CHAE, Y.K.KIM

Research Reactor Development Group,
Korea Atomic Energy Research Institute
111 Daedeok-daerho Yuseong, Daejeon
305-353 Korea (Rep.)

*Corresponding author: cpark@kaeri.re.kr

ABSTRACT

A new research reactor construction project (hereafter, “KJRR project”) was launched in April, 2012, in order to secure the supply of key radioisotopes for medical and industrial applications and to develop and qualify the core technologies of research reactors (RRs). The KJRR project aims to establish a RR with 15 MW and utilization facilities for radioisotopes production and the relevant research and development (R&D) at Kijang-Gun, Busan City in Korea. The Korea Atomic Energy Research Institute (KAERI) entrusted by the government has proceeded with the project in cooperation with the Kijang municipality. The KAERI undertakes system design, licensing and commissioning of the facility while the Kijang municipality is assigned to provide the infra-structure like water or electricity. Preliminary safety analysis report (PSAR) is being prepared to apply for construction permit. The KJRR is under detail design and is expected to put into operation in 2018. This paper describes the current status of the KJRR project and the basic design features of the KJRR.

1. Introduction

As one of major national projects for nuclear science and engineering in Korea, the KJRR project was commenced in order to develop the core RR technologies for strengthening the competitiveness of the RR export and also to stabilize the supply of key radioisotopes for medical and industrial applications [1, 2].

In principle, the KJRR, which will be constructed in Radiation Medical Science and Industrial Complex located in Changan-Up, Kijang-Gun, Busan City, is designed to dedicate to the RI production and neutron transmutation doping (NTD) service in order to cope with the gradually growing demands of radioisotopes (RIs) and NTD service. So no beam tubes are employed in the KJRR. In particular, the production of Mo-99, the source of Tc-99, which is one of key RIs for medical sector, is one of important duties of the KJRR. Hydraulic driven NTD devices are installed for the silicon irradiation service which is expected to be gradually growing.

Another objective is to develop and qualify the upgraded research reactor concept with state-of-the-art or unsecured technologies for RRs such as a bottom mounted CRDM (Control Rod Drive Mechanism), plate type fuel using U-Mo materials, Fission Mo production process with LEU target, and hydraulic system for NTD (Neutron Transmutation Doping) service.

2. **Project Plan and Schedule** [2, 3]

Fig. 1 shows the milestone of the KJRR project. According to the plan, the KJRR will be put into operation in the middle of 2018. For the first couple of years, conceptual and basic designs had been performed to prepare the preliminary safety analysis report (PSAR) for the application of the construction permit (CP). The submission of the application documents including the PSAR to the regulatory body is expected in the end of 2014. And the construction is expected to be started around at the end of 2015 after deep reviews and approval of the PSAR by the regulatory body. The actual schedule will depend on the budget and the technology developments such as the bottom mounted CRDM and the qualification test of plate type U-Mo fuel. In practice, the schedule was delayed one and half years due to the government budget plan for the KJRR and the amendment of nuclear regulation for RRs. Regulation change from one-step license to two-step license for RRs resulted in more than 6 months delay of PSAR submittal for CP application.

Major facilities to be built in this project are as follows:

- ✓ 15 MW Research Reactor and Reactor building
- ✓ Radioisotopes Production Facility (RIPF) and R&D Facility
- ✓ Fission Mo Production Facility (FMPF) and LEU Target
- ✓ Radio-waste Treatment Facility
- ✓ Neutron Irradiation Facility

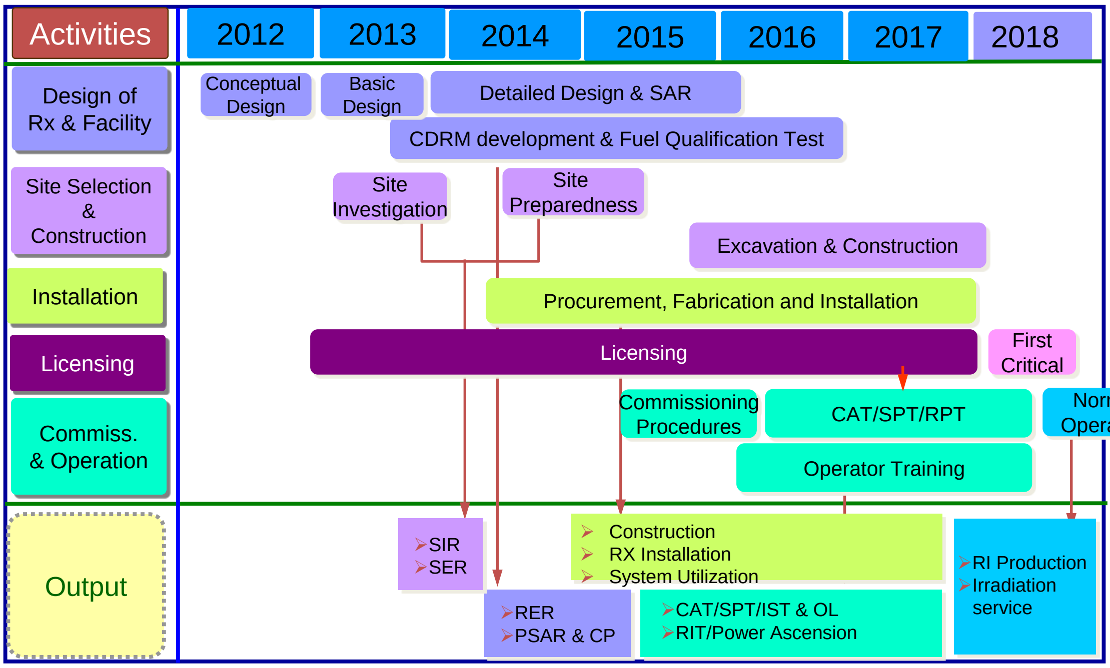

Fig. 1 Milestone of the KJRR project

3. Utilization Requirements and Basic Design Features

The design of the KJRR generally starts from the establishment of top-tier requirements and design bases, which considers many aspects of the RR project such as the general characteristics, safety, performance, design and construction, licenses, and budget etc.

Focusing the reactor facility, basically, the reactor should be designed to meet the utilization purposes. The KJRR will be mainly utilized for radioisotope production, NTD service, and the related research activities. Hence, the design bases as general principles for the engineering design had been carefully prepared to satisfy its purpose.

The utilization requirements for the capacity of major RIs production and NTD service are as follows [4].

- ✓ Mo-99 : ≥ 100,000 Ci/yr
- ✓ I-131 : ≥ 4,000 Ci/yr
- ✓ Ir-192 : ≥ 300,000 Ci/yr
- ✓ NTD : ≥ 150 ton/year

The conceptual and basic design has been conducted to meet the design bases including design and performance requirements. The basic design features of the KJRR are listed in Table 1 [5]. The KJRR will enable to operate the reactor over 300 days per year and to get 60% burn-up pertinently to produce the required neutron flux for meeting the above performance requirements.

A target holder with LEU to produce Mo-99 will be loaded and unloaded while the reactor is on power operation, to produce more than 2,000 Ci/week. Other radioisotope production requirements for Ir-192 (6,000 Ci/week), P-33, Lu177 (50 Ci/week), I-131 (8,0 Ci/week), and Co-60 (medical purpose) are also considered [4].

The irradiation holes for Si ingot are designed to meet the NTD capacity and to cope with the need from irradiation service market. They are designed to accommodate 6, 8, and 12” (OD) ingot [3, 4]. The selection of ingot size will depend on the market needs.

The design of the KJRR ought to comply with the Korean Nuclear Law, regulatory requirements and guidelines. In addition, the regulatory submittals will adhere to internationally applicable standards and guidelines such as the IAEA safety standards. In addition to that, the technical requirements and criteria for such kind of industrial codes and standards are also applied as detailed technical requirements. The safety requirements must be established and applied coherently with other requirements for human performance, quality, and security. An information service system for the facility management must be provided together with the facilities for the integrated management and experience feedback for operation and utilization. The design shall minimize the possibility of risk occurrence by the mistakes of users. All practical efforts shall be made to prevent and mitigate nuclear or radiation accidents.

Table 1. Basic design features of the KJRR

Parameter	Value
Power	15 MW
Reactor Type	Open-tank-in-pool type
Max. thermal neutron flux	> 3.0×10^{14} (n/cm^2s)
Annual operation	~300 days
Life time	50 year
Fuel	Plate type, U-7Mo (19.75% enriched) in Al matrix with Al Clad
F-Mo Target	UAlx plate type (LEU, 2.6 g/cc)
Reflector	Be, Graphite, and Al
Coolant and Cooling method	H_2O, downward forced convection flow
Decay heat cooling	Safety Residual Heat Removal System & Natural circulation by passive flap valves
Reactor Protection System	Digital I&C Drop by gravity (CARs & SORs)
Reactor building	Confinement
Irradiation holes for NTD and RI production	6, 8, and 12 inch in diameter 6 U-Mo target site and 9 irradiation holes

4. Design Characteristics of Major Systems

1) Fuel [5, 6, 7]

The fuel assembly is a typical box-type fuel with flat fuel plates, which has been proven with long irradiation experiences in many research reactors worldwide. A total of 21 fuel plates constitute a fuel assembly, and a fuel plate is composed of a fuel meat with the cladding. Two types of fuel assembly, standard fuel assembly (SFA) and follower fuel assembly (FFA) are used for the KJRR, as shown in Fig. 2. The fuel assemblies are the same shape for flexibility in-core fuel management.

The fuel meat is made of fine and homogeneous dispersion of uranium-molybdenum (U-7Mo/Al-5Si) particles in aluminum matrix. 5 wt% Si is added to restrain the reaction of U-Mo particles with Al. The U-235 enrichment for the equilibrium core is 19.75 weight %. However, fuels with 2 different uranium density will be used for the initial core to obtain flat power distribution. (19 inner plates of 8.0 gU/cm^3, 2 outer plates of 6.5 gU/cm^3).

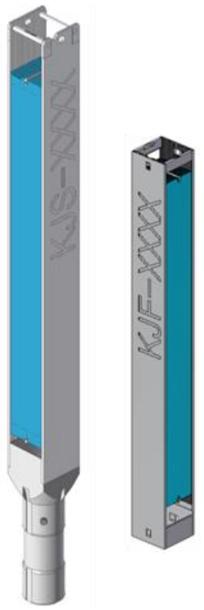

Fig. 2 SFA and FFA

Fuel Qualification

Innovative technologies and facilities will be applied to the KJRR. Particularly, U-Mo plate type fuels based on U-7Mo dispersed in Al-5Si will be used for the KJRR. U-Mo fuels have a strong point to make high density fuel meat for RRs. The KAERI is unique manufacturer to make U-Mo fuels by using atomization technique. This is the first try to apply the U-Mo fuel to the RR in practice, and which could drive RR fuel change from high-enriched fuel to low-enriched fuel in compliance with RERTR program.

The performance and integrity of U-Mo fuel will be qualified by irradiation tests in two research reactors, the HANARO in Korea and the ATR in the USA. In the HANARO, irradiation tests of mini-plate due to limitation of test rig are supposed to be performed in three (3) times for the burn-up targets of 45%, 60%, and 90%, respectively, named as HAMP 1, 2, and 3 tests. Dimension of mini-plates for HAMP-1 and 2 is 35mm in width and 130mm in length while that for HAMP-3 is 35mm in width and 640mm in length. First irradiation test (HAMP-1) was finished in June 2014. Second and third tests (HAMP-2, 3) are waiting for irradiation at the end of Oct. 2014. All tests including PIE (Post Irradiation Examination) will be finished in June 2017.

Regarding the full scale test, the irradiation test of a prototype fuel assembly, which was manufactured by the KAERI and already delivered, will start at ATR in April 2015 and finish in Feb. 2016. Before that, the out-pile test such as flow test and mechanical characteristics tests will be done in KAERI by March 2015.

2) Reactor core [5, 9]

The main purpose of the KJRR is to produce radioisotope such as Mo-99, I-131, I-125, Ir-192, etc. and neutron transmutation doping (NTD) of Silicon. For these applications, the reactor core consists of a total of 22 fuel assemblies; 16 SFAs and 6 FFAs, as shown in Fig. 3. The core is positioned in a core box which can prevent core uncovered at emergency situation. Irradiation holes for the production of Mo-99 and other radioisotopes are provided in-between fuel assemblies inside the core. The overall core geometry is configured as 7 x 9 rectangular arrays with active height of 60cm.

Maximum 6 fission moly targets can be loaded during the normal operation. 3 flux traps and 9 irradiation holes, where on-power loading is possible, are employed to produce Mo-99 and other radioisotopes. The irradiation holes for NTD are large to house the Silicon ingot of diameter from 6 inch up to 12 inch. Six (6) NTD holes are provided outside the core, which are surrounded by the reflectors of beryllium and graphite to obtain the required thermal flux level. One (1) HTS and two (2) PTS are located inside or outside of the core box, too.

The sizes and locations of experimental holes are optimized and well-arranged by considering a convenience for users and an interference with other in-pool structures such as the reactivity control units.

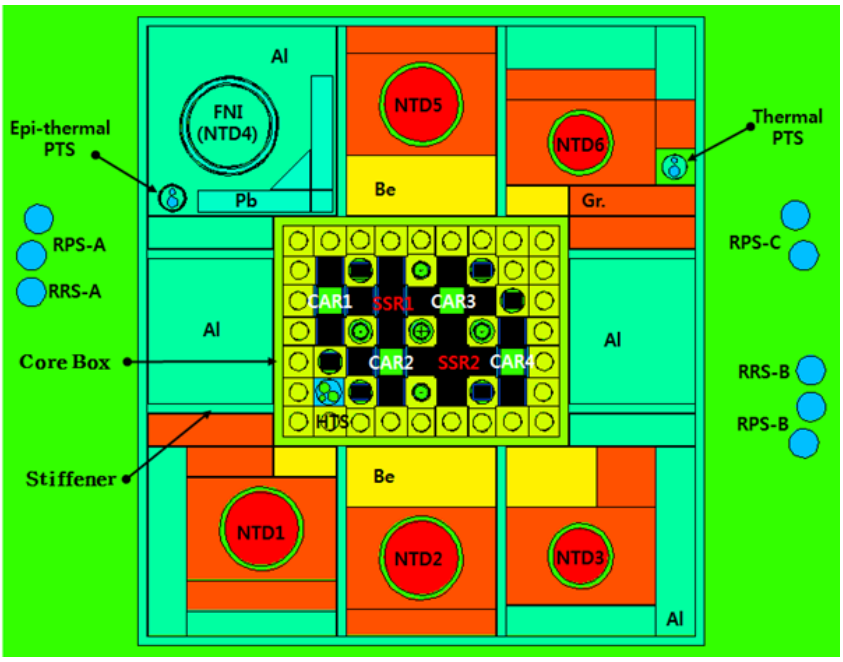

Fig. 3 Reactor core configuration

4) Reactor Assembly and CRDM/SSDM [5, 10, 11]

The reactor assembly (RA) is composed of reactor structure assembly (RSA), fuel assemblies, reflectors, and reactivity control units, as shown in Fig. 4. The RSA comprises the outlet plenum, grid plate, upper guide structure, and detector housings. It provides the flow path for primary coolant and supports for fuel assemblies, reflectors, neutron detectors, etc. It also supports the guide structures of two kinds of Control Absorber Rod (CARs) and Second Shutdown Rods SSRs. The RSA is secured to the bottom of the reactor pool by RSA anchor bolts.

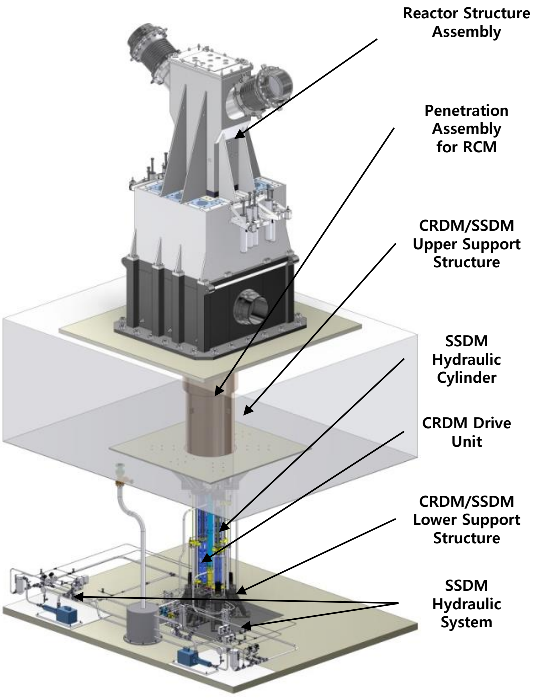

Fig. 4 Reactor assembly and CDRM/SSDM

There are two kinds of reactivity control mechanisms; Control Rod Drive Mechanism (CRDM) and Second Shutdown Drive Mechanism (SSDM). Four (4) CRDMs, with command from the Reactor Regulating System (RRS), control the core reactivity during the normal operation. A CRDM inserts or withdraws a CAR or maintains it at required position using a stepping motor. All CARs are dropped by gravity when a reactor trip is required by the Reactor Protection System (RPS) or by the Alternate Protection System (APS). Two SSDMs, as an independent shutdown system, provide a diverse means of reactor shutdown by the gravity drop of SSRs whenever a reactor trip is required by the RPS or by the APS. The neutron absorber of CARs and SSRs is hafnium.

CRDM/SSDM Development

The locations of CRDM, whether it is positioned above or below the reactor core, have their own strong points and drawbacks. It is usually known that a reactor bottom mounted CDRM is advantageous from the utilization while the reactor top mounted CDRM has strong point from the safety and maintenance point of view. The choice is dependent on the design to harmonize with other systems and equipment.

For the KJRR, a bottom mounted CDRM/SSDM have been decided for the reactivity control of the core. Due to expensive cost for the import of CRDM from abroad, the KAERI decided to develop it by itself and a bottom mounted CRDM is being developed in accordance with the KJRR project schedule. All key components such as electromagnet, extension shaft adapter, guide tubes, seal valve and connectors, as shown in Fig. 5, were developed and their performance tests also finished in Oct. 2014.

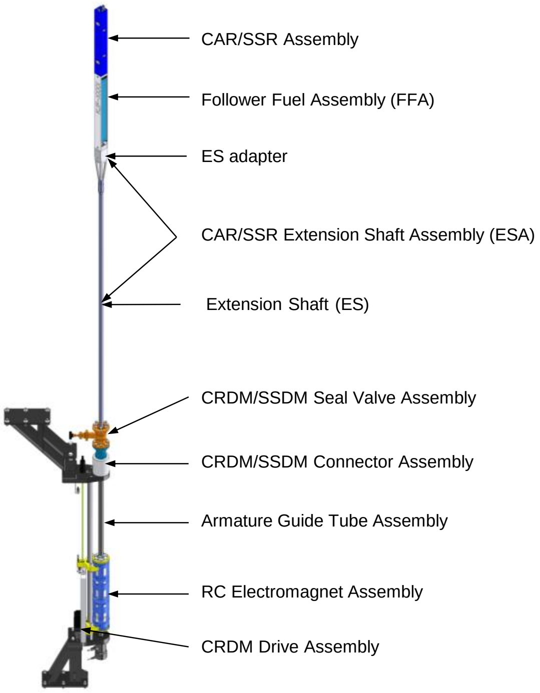

Fig. 5 Bottom-mounted CRDM

Accompanied schedule to complete the CRDM/SSDM development is as follows.

- ✓ Test facility for performance and endurance tests : Dec.2014
- ✓ Manufacturing of Q Class prototype CRDM/SSDM : May. 2015
- ✓ Performance and endurance tests of CRDM/SSDM : June to Dec., 2015
- ✓ Test facility for seismic test : Mar.2016
- ✓ Seismic tests of CRDM/SSDM : Mar. to June.2016

4) Cooling system

Cooing and connected systems of the KJRR, as shown in Fig. 6, is composed of the Primary Cooling System (PCS), the Secondary Cooling System (SCS), the Pool Water Management System (PWMS), the Hot water Layer System (HWLS), the Safety Residual Heat Removal System (SRHRS) and the Neutron Transmutation Doping Hydraulic Rotation System (NTDHRS).

The PCS circulates demineralized light water to the reactor assembly to remove the heat generated in the fuel and other reactor components. The heat is transported by the coolant to heat exchangers where it is transferred to the SCS, and then the heat is discharged to the atmosphere by a cooling tower. Two flap valves are installed on the reactor outlet pipe in order to provide the natural circulation flow paths for core decay heat removal when the PCS pumps are off.

The PWMS is designed to remove decay heat from the spent fuels, to cool the reactor pool water during the normal operation and the reactor shutdown. It controls and maintains the quality of the primary coolant and the reactor pool water such as visual clarity, purity, and radioactive content. The system also provides the functions of storing the reactor pool water for maintenance works inside the reactor pool and refilling the reactor pool after the maintenance work is completed.

The HWLS is installed to form the hot water layer at the top of the reactor pool and service pool to reduce the radiation level near pool top during the normal operation. The system has a purification function to remove traces of corrosion, fission or radioactive impurities.

To secure the core decay heat removal against the case that all PCS pumps are not available, the SRHRS is installed. After shutdown with unexpected PCS pump failures, core decay heat is initially cooled by the fly wheels of the PCS pumps for a while, and then the SRHRS is activated to cool the fuel continuously. For the long term cooling, decay heat is removed by natural circulation through the flap valves installed on the core outlet pipes.

The NTDHRS is to provide the flow to hydraulically rotate the Si ingot for NTD which is on the NTD hydraulic device. The system also cools the irradiation can and the reflector. It is being developed [12].

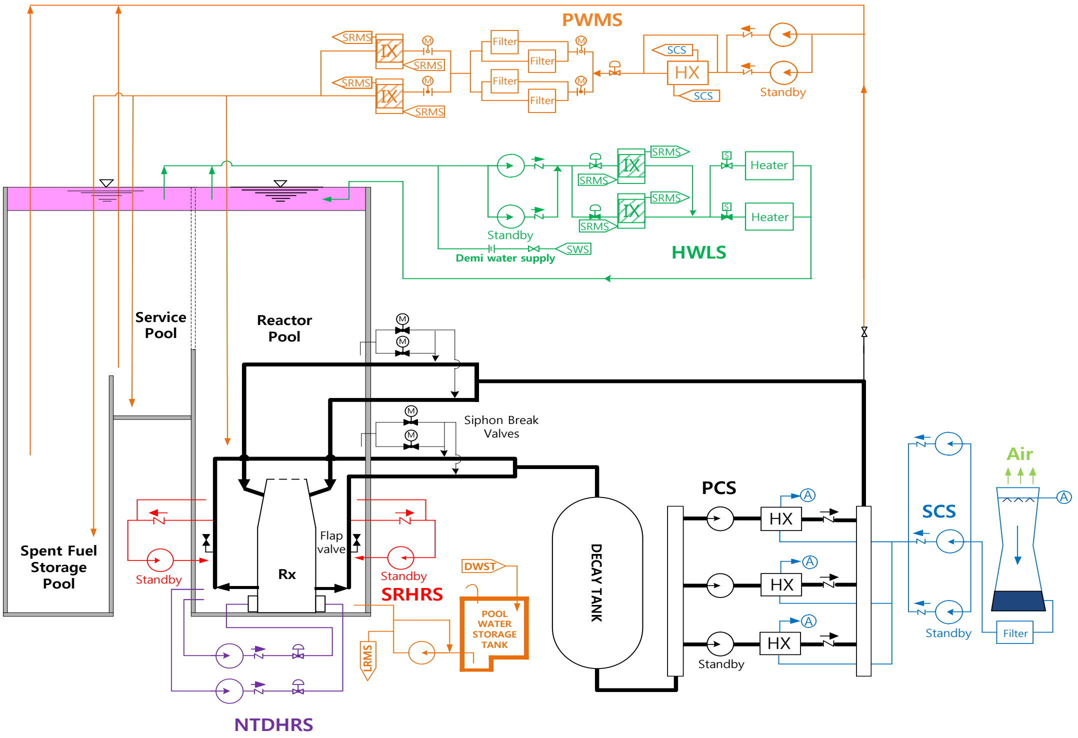

Fig. 6 Schematics of the KJRR cooling systems

5) I&C

The instrumentation and control (I&C) systems are to control, protect and monitor the reactor facility, which is composed of Reactor Protection System (RPS), Reactor Regulating System (RRS), Alternate Protection System (APS), Post-Accident Monitoring System (PAMS), Radiation Monitoring System (RMS), Information Processing System (IPS), Process I&C System (PICS), Automatic Seismic Trip System (ASTS), Main Control Room (MCR) and Supplementary Control Room (SCR). Most I&C systems of the KJRR are implemented by digital computer technology. All I&C systems and equipment are designed, constructed and maintained in such a way that their specification, verification and validation, quality and reliability are commensurate with their classification [5].

6) Reactor building

Fig. 7 shows a general arrangement (GA) of the reactor building. In the figure, the left side is the reactor area and the other is for FM and RI productions. Lots of design factors regarding accessibility, mobility, usability, safety, economy, etc. of material, components and human have been took into consideration in building arrangement. The reactor pool has the same level with the ground. The spent fuel storage is between the reactor pool and the Fission Molybdenum (FM) area. Of course, the reactor area and the FM area are separated by the wall. The inclined tunnels connect the spent fuel storage pool and the FM area. Heavy components such as the heat decay tanks, the primary cooling pumps and so on are mainly placed on the first and second basements [5].

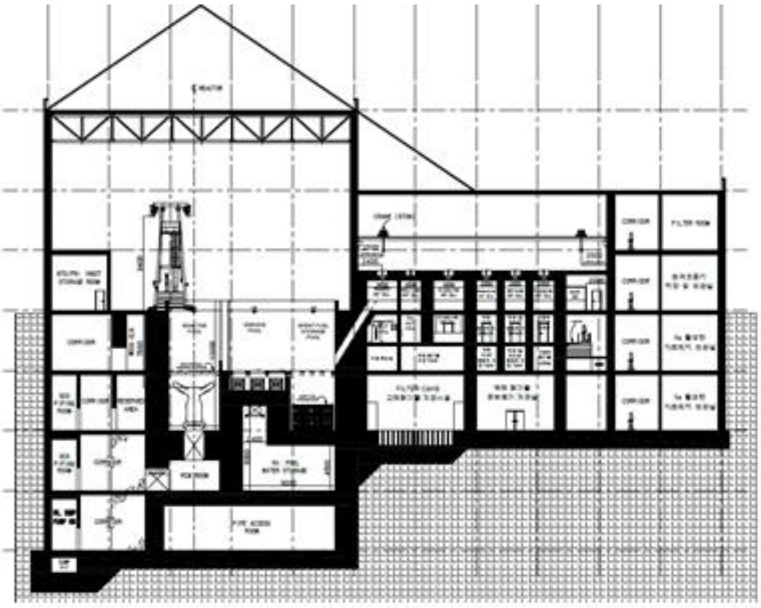

Fig. 7 General arrangement of the reactor building

7) Site and Metrological Tower

The KJRR site is in a suburb of Busan, the 2nd largest city in Korea, which has an international airport and a large harbor with highways. Those well-established infrastructures provide good accessibility to the site as well as easy transportation of products from the KJRR. The site was selected from competition among 9 local governments that have expressed their wish to host the KJRR. The site is also very close to several existing nuclear power plants in operation. Thus, it is expected that there is no difficulty in the site characteristics and in the public acceptance as well.

The meteorological tower was constructed at the site and started gathering weather data from June 2014. The site leveling works begin in June 2014 and will be finished in the first half of 2015. On-line data transferring system from the site was established in Sep. 2014.

Finally, the KJRR will appear a couple years later in reality, as schematically shown in Fig. 8.

Fig. 8 Bird's-eye view of the KJRR

5. Concluding Remarks

The KJRR project was started; 1) to make up the advanced technology related to research reactor, 2) to increase self-sufficiency in terms of medical and industrial radioisotope supply, and 3) to enlarge the supply of NTD silicon doping for growing power device industry.

The basic design of the KJRR has been completed at the end of 2013. Basic engineering and detail design is undergoing and the preliminary safety analysis report (PSAR) is being prepared to apply for the construction permit (CP) in the late of 2014.

After receiving a CP, we will move on the next stages that includes detail engineering, manufacturing major components and the construction of reactor building and auxiliary buildings. And then we will obtain operating license and then will conduct fuel loading, commissioning and pre-service inspection. In the long run, the KJRR will be realized in the middle of 2018.

References

[1] I.C. Lim et.al., “Plan of New Research Reactor Construction in Korea”, ICRR-2011, Aug., Poland, 2011.

[2] I.C. Lim et.al., “Progress of Ki-Jang Research Reactor Project”, RRFM-2013, Belgium, 2013.

[3] S.I.Wu et.al., “New Research Reactor Project in Korea”, IGORR-2013, Oct., Korea, 2013.

[4] Y.H. Yoo, Design Bases for KJRR, KJ-070-KF-403-001, P1, KAERI, 2014.

[5] Preliminary Safety Analysis Report, to be issued in Dec., 2014. (in Korean)

[6] Y.W.Tahk, Fuel Design Report, KJ-372-KN-422-002, P0, KAERI, June, 2014.

[7] J.S.Yim et.al., “Test Plan for Mini Plates Irradiation and PIE for U-7Mo Fuel Qualification”, RRFM, Slovenia, 2014.

[8] Y.W.Tahk, “Fuel Performance Evaluation of Mini-plate Irradiation Test of U-7Mo Dispersion Fuel for KJRR”, IGORR-2013, Oct., Korea, 2013.

[9] C.G.Seo et.al., “Innovative Design Concepts for the Ki-Jang Research Reactor”, KNS spring meeting, May 30-31, 2013.

[10] J.H.Lee et.al., “Conceptual Design of Bottom-mounted Control Rod Drive Mechanism”, KNS spring meeting, May 30-31, 2013.

[11] S.H.Kim et.al., “Bottom-mounted Reactor Shutdown Mechanism”, KNS spring meeting, May 30-31, 2013.

[12] K.J.Park et.al.,”Experimental Study on Hydraulic Rotation Device for Neutron Transmutation Doping”, KNS spring meeting, May 29-30, 2014.