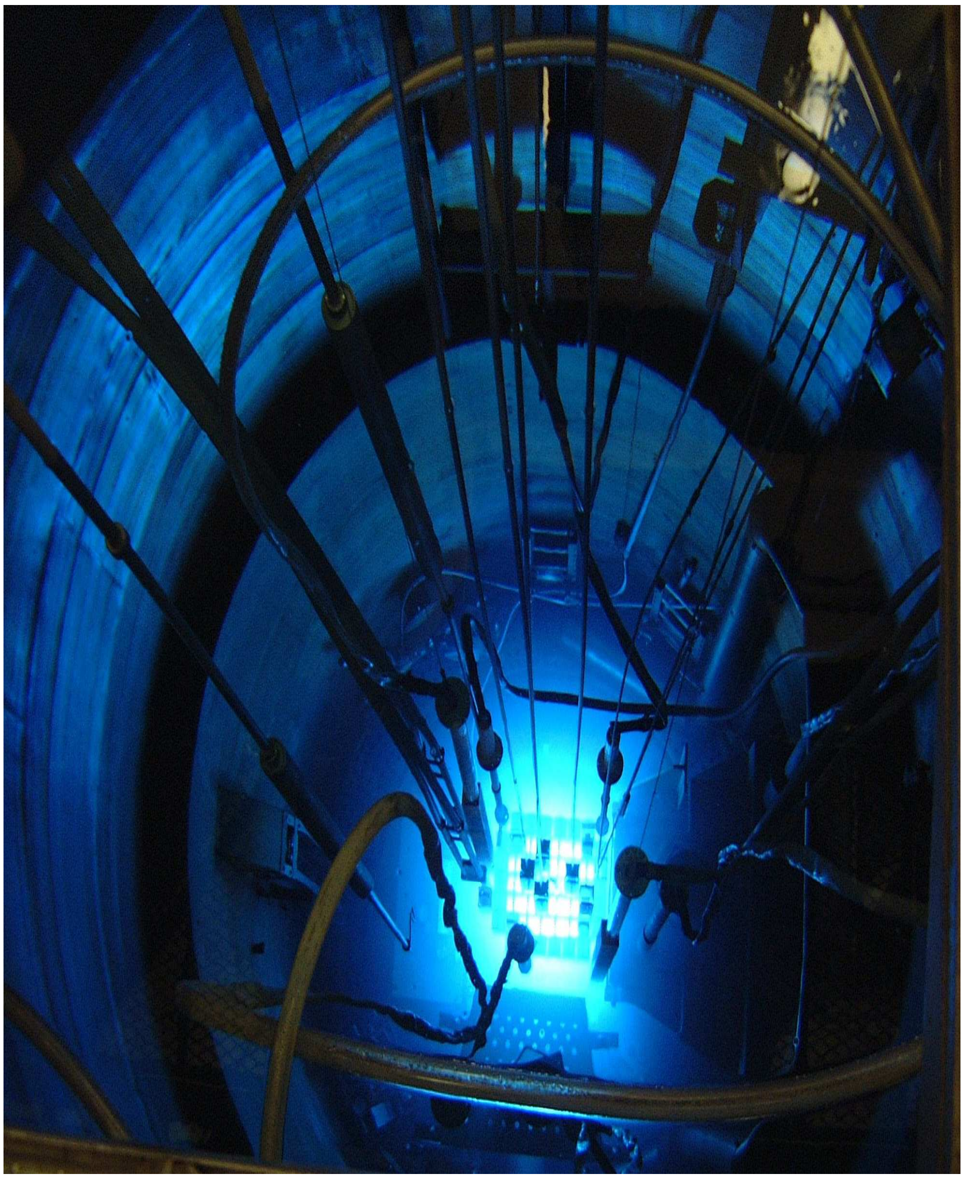
Possible Cooperative Projects for Utilization of the DPRK's IRT-2000 Research Reactor

Ira N. Goldman and Pablo Adelfang
Sean O'Kelly



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Introduction

IRT-2000 Research Reactor: Basic Facts/Chronology

- Soviet-designed/supplied reactor and fuel
- Pool-type, light-water cooled, moderated, 1.2 x 10^{14} flux
- 1965 - first criticality 2 MW using 10% enriched fuel (EK-10)
- 1974 - changed to 80% enriched fuel and increased to 4MW
- 1984 – changed to 36% enriched fuel (IRT-2M fuel)
- 1987 – upgraded to 8MW
- Spent fuel is in storage
- Similar to Libya, Uzbekistan, and MEPhI (Moscow Engineering Physics Institute, Russia)

What are Research Reactors Good For?

- Radioisotope production (medical, industrial, agricultural)
- Education & Training
- Environmental, industrial, cultural heritage analyses
- Material science investigations
- Supporting power reactor programmes
- Fuel testing and qualification

Assumptions

- Satisfactory progress in Six Party talks, implementation of commitments
- NPT adherence
- Compliance with IAEA full-scope safeguards agreement
- Conclusion and implementation of IAEA Additional Protocol

Non-Proliferation Benefits

- Conversion to LEU (and removal of fresh and spent HEU) has a clear non-proliferation benefit.
- Fresh HEU is “direct-use” material.
- Spent HEU fuel is low burn-up and radiologically cool, easily reprocessed to recover HEU.
- Removal of all HEU eliminates potential fissile material source.

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[1] The views presented in this paper are those of the authors and are not official views of the Nuclear Fuel Cycle and Materials Section, Division of Nuclear Fuel Cycle and Waste Technology, International Atomic Energy Agency.

- Slightly increased plutonium (Pu) production in new LEU fuel (vice old HEU fuel) but still very low.
- Significant (Pu) production in IRT-2000 LEU fuel not possible (10-20 grams Pu produced per year depending upon IRT-2000 schedule).
- Utilization activities (e.g. RI production) would not add new technical capabilities of proliferation significance.

Possible IRT-2000 Cooperative Projects

Addressing IRT-2000 Infrastructure

- LEU conversion (Libya, Uzbekistan, Russia, U.S., Vietnam)
- Instrumentation and Control Upgrading (Libya, Russia, U.S., Uzbekistan)
- Spent Fuel Return (Czech, Hungary, Russia, U.S., Uzbekistan)

(possible cooperating partners as noted; each activity to be explained later in detail)

Enhancing Utilization and Scientific Applications

- Isotope production (Mo-99 and other) (ROK, China)
- Education and Training (nuclear institutes, domestic universities, ROK)
- Neutron Activation Analysis/NAA (domestic users)
- Silicon Transmutation Doping (ROK, China)
- Neutron Radiography (commercial application)
- Neutron Scattering (ROK/Hanaro, China/CARR)

Program Overview/Schedule

Infrastructure Activities (implement in parallel)

- LEU Conversion: 2-3 years; $1.5-2 million
- Spent Fuel Return: 2-3 years; $6-10 million
- Instrumentation & Control (I&C) Upgrade: 2-3 years; $1.5-2 million
- Other refurbishment ($1-4 million)

-- Short-Term Measures

- Participate in Reduced Enrichment for Research and Test Reactors (RERTR) and Research Reactor Fuel Management (RRFM) Conferences
- Fellowships/training at Argonne National Laboratory (ANL-U.S.) and/or Research Reactors that have recently converted to LEU
- Visits to Research Reactors that have already shipped Russian-origin spent fuel and/or have upgraded I&C systems.
- Participation in IAEA meetings and activities.

Applications (1 – 4 years, after LEU core)

- Isotope production: $2-5,000,000
- Education and Training: $100,000
- Neutron Activation Analysis (NAA): $300,000
- Silicon Transmutation Doping: $250,000

- Neutron Radiography: $100,000
- Neutron Scattering: $500,000+

-- Short-Term Measures

- Visits of DPRK personnel to well-utilized Research Reactor facilities
- Personnel training via fellowships at Research Reactors carrying out these applications.
- Procurement of equipment (slightly later)

Role of DPRK Nuclear Experts

- Utilize to greatest extent existing skills and capabilities of DPRK nuclear scientists, engineers, and technicians.
- Past experience – including facilities and technical expertise – related to reactor physics calculations, radiochemistry, isotope production, etc. relevant to most activities
- Some specialized technical training for new research reactor applications may be required
- Business and marketing skills will need to be enhanced
- Promote cultural sensitivity and other related skills in order to pursue international cooperative ventures.
- Approximately 200-500 personnel may eventually be employed at the IRT-2000, its ancillary facilities, experiments, and programs.

Addressing IRT-2000 Infrastructure

- LEU conversion: reactor core conversion calculations/studies can be performed by DPRK reactor physics scientists with training
- Spent Fuel Return: DPRK experience (especially technicians) in preparation (fuel measurements and characterization) and re-packaging of 5MW reactor spent fuel directly relevant
- Instrumentation and Control Upgrading: IRT staff can develop new system specifications and design, system integration and components likely to be externally procured

Enhancing Utilization and Scientific Applications

- Isotope production: target fabrication, irradiation rig design, reactor physics calculations, radiochemistry can all be performed with existing staff in DPRK (reprocessing skills directly applicable).
- Education and Training: existing staff can develop courses and lectures
- Neutron Activation Analysis/NAA: existing technicians can be trained
- Silicon Transmutation Doping: existing technicians can be trained
- Neutron Radiography: existing technicians can be trained
- Neutron Scattering: substantial training required for development of instrument scientists and for scientific user community.

Addressing IRT Infrastructure

- IRT-2000 is a “middle-age” research reactor.
- A survey, review, and analysis will need to be conducted to assess the state of various systems and components.
- It is apparent that a number of activities will need to be carried out in order to assure safe and effective operation for ~20 years.
- Reports indicate that the reactor needs fresh fuel to operate
- Conversion to LEU would be required.
- In addition, instrumentation and control system is probably original and needs to be modernized and upgraded.
- IRT-2000 spent fuel is eligible to be returned to Russia.

LEU Conversion

- Conversion experiences in Libya (completed) and Uzbekistan (ongoing) are directly applicable to IRT-2000.
- IRT-4M LEU fuel is commercially available (contract) from Atomenergoprom TVEL (Novosibirsk, Russia), probably can be used to convert IRT-2000.
- IRT-2000 must perform a variety of calculations and studies in order to determine the LEU core configuration and to revise Safety Analysis Report (SAR).
- Process requires 2-3 years, ~$1.5-2 million
- Kick-off and regular coordination meetings, procurement, expert missions including fuel acceptance, etc. (see sample schedule)
- U.S., Libya, and Uzbekistan can provide expertise and examples in regard to core calculations and studies.
- IAEA can assist with overall project management, procurements, provision of expert services, etc.
- Possible partners: Libya, Russia, U.S. Uzbekistan, Vietnam, IAEA
- Major Activities – share experience, expertise, cooperate to:
  1. Perform neutronic and thermohydraulic core conversion studies (steady-state and transient)
  2. Model new LEU core
  3. Revise safety analysis report (incl. operating limits and conditions)
- IAEA assistance for:
  1. Project coordination and international procurement
  2. Arrange experts to assist with quality assurance/quality control (QA/QC) and fuel acceptance
  3. Provide equipment to monitor fuel performance

LEU Conversion Schedule

Domestic Preparations

Prepare calculations	6-9 months
Complete Safety Analysis Report (SAR)	6-9 months

Amend SAR	3-6 months
Obtain LEU license	1-3 months
TOTAL	16-27 months

International Fuel Purchase

Prepare bid specifications	2-4 months
Solicit bids	2-4 months
Evaluate bids	1 month
Negotiate purchase contract	1-3 months
Sign Contract	1-2 months
Fabricate Fuel	6 months
Deliver Fuel	1-2 months
TOTAL	14-20 months

- Preparatory activities (prior to actual physical change of new core with LEU fuel rods) can take place ***before*** IAEA safeguards are in place:
  1. Attend RERTR and RRFM conferences, exchanges, meetings
  2. Training (fellowships and SVs) at ANL/U.S. and/or RRs that have recently converted

Delivery of nuclear materials (new core consisting of LEU fuel rods) can only take place ***after*** IAEA safeguards agreement and subsidiary arrangements are in place

Instrumentation & Control (I&C) Upgrading

- Older RRs can replace existing I&C systems with new digital equipment to enhance safety and operability.
- Several RR I&C upgrade projects have recently been completed, are underway, or planned (Ghana, Libya, Kazakhstan, Romania, Vietnam).
- I&C upgrades have often been performed in parallel with LEU conversion.
- I&C systems are commercially available, but some reactors have undertaken projects on their own.
- Approximately 2 year process, $1.5-2 million from initial planning to installation and testing.
- Possible partners: Libya, Kazakhstan, Romania, Russia, U.S., Uzbekistan, IAEA
- Major Activities: share experience, expertise, cooperate to:
  1. Prepare new system specifications
  2. Issue international tender, evaluate bids, selection, and contract award
  3. Installation and testing of new I&C system
- IAEA assistance for:
  1. Project management
  2. Preparation of specifications
  3. Procurement and installation

-- Upgrading Schedule

Domestic Preparations

Prepare system specifications	12 months

International Procurement

Prepare bid specifications	2-4 months
Solicit bids	2-4 months
Evaluate bids	1 month
Negotiate purchase contract	1-3 months
Sign Contract	1-2 months
Fabricate System	12 months
Install and Test System	2-4 months
SUB-TOTAL	12-24 months
TOTAL	24-36 months

IRT Spent Fuel Return

- Russian-origin HEU (and LEU) fresh and spent fuel from RRs eligible for return to Russian Federation under DOE/NNSA Global Threat Reduction Initiative, Russian Research Reactor Return Program.
- Spent fuel successfully shipped from Uzbekistan (2006), Czech Republic (2007), Latvia (2008); shipment from Hungary later 2008
- Bulgaria, Kazakhstan, Libya, Romania, Serbia, Vietnam being planned.
- Facility preparations, transport, and administrative arrangements (with Russian Federation) are complex.
- Spent fuel return, reprocessing in Russia, $6-10 million.
- Approximately 20 DPRK experts could be involved.
- Substantial experience and "lessons learned" already available, good opportunity for partnerships.
- Possible partners: Czech Republic, Hungary, Russia, U.S., Uzbekistan, IAEA
- Major Activities – share experience, expertise, cooperate for:
  1. Project planning and coordination
  2. Spent fuel measurements, packaging, cask loading
  3. Facility preparations and modifications
  4. Regulatory and administrative requirements
- IAEA assistance for:
  1. Project management
  2. Guidelines and training
  3. Procurement

Domestic Preparations

Spent Fuel Measurement/Characterization	6-9 months
Site Modifications	12 months
Cask Loading	3 months
TOTAL	12-24 months

International Preparations

Unified Project (Russia)	12-18 months
Transit Approvals	12 months
Transport	1 month
TOTAL	18-24 months

Enhancing Utilization and Scientific Applications

- IRT-2000 is in principle capable to carry out a wide variety of activities related to commercial (medical, industrial, agricultural), nuclear energy, and scientific missions.
- Review of IRT-2000 infrastructure updating should be paralleled by development of a strategic and business plan for the research reactor.
- Important to clearly identify potential domestic users, and to establish relationships.
- Potential external partners are available, especially with ROK, Japan, China(?).

Radioisotope Production (RI)

- Expanding market for RIs and especially Mo-99, but no Mo-99 production on Korean Peninsula.
- China does **NOT** produce Mo-99, expanding nuclear medicine sector and huge potential market.
- ROK (KAERI) producing LEU foil for Mo-99 fission targets, has decided not to produce Mo-99 in Hanaro RR.
- Possible DPRK Isotope Production Program: to encompass IRT-2000, Isotope Production Laboratory (Yongbyon), and Atomic Energy Research Institute Cyclotron – have the necessary irradiation facilities, hot cells, and radio-chemical skills.
- IAEA Mo-99 Coordinated Research Project (CRP) disseminating LEU and neutron activation technology, participants rapidly gaining expertise.

Radioisotope Production – Mo-99

- Mo-99/Tc-99m most widely used medical radioisotope in world.
- 70-80% of nuclear medicine procedures worldwide use Mo-99.
- 20 million medical diagnostic procedures/year in USA, increasing everywhere 8-12%/year; Asia still underdeveloped in use.
- Tc-99m is combined with different molecules for diagnoses related to Bone, Cardiac, Lung, Thyroid, Brain, Gastrointestinal, Liver, Biliary system, Lymphatics, Renal, Labelled Cells, Oncology:

        - Bone – metastases to bone from cancers; injuries (trauma, sports), infection, Pagets (metabolic disease)
        - Cardiac – ischemia, infarction, review of chest pain, transplants, review before and after stents
        - Gastrointestinal – various process, disease diagnosis
    - Rapidly expanding nuclear medicine market in ROK – in June 2007, 94 Positron Emission Tomography (PET), PET/CT centers (only 7 in 2002), and in Asia.
    - Mo-99 produced in reactors; must be quickly processed, shipped.
    - PET isotopes produced in accelerators AT or very close to the hospital/PET center.

Radioisotope Production – Other
Radioisotopes can be produced in Reactors (longer-lived isotopes) and Cyclotron/Accelerator (short-lived isotopes).

- Medical radioisotopes, include:
    - Imaging
        - -Reactor: Carbon-14, Cesium-131, Cobalt-57,60, Gallium-67, Thallium-201
        - -Accelerator (for Positron Emission Tomography or PET): Carbon-11, Nitrogen-13, Rubidium-82, Oxygen-15; Fluorine-18
    - Therapy
        - Reactor: Actinium-225, 227, Holmium-166, Indium-111; Iodine-123, 125, 131; Lutetium-177, Phosphorus-32, Samarium-153, Strontium-89, Tin-117m, Yttrium-90
- Industrial Radioisotopes: Cadmium-109, Germanium-68, Iridium-192, Iron-55, Nickel-63, Selenium-75, Sodium-22
- Possible partners: ROK, China, IAEA Mo-99 CRP
- Objective – develop capability to produce for domestic market, possible regional exports (ROK, Phillipines, etc.)
    1. Assess infrastructure and technical requirements for RI/Mo-99 production.
    2. Perform required neutronic and thermohydraulic calculations, irradiation rig design, safety analyses, etc.
    3. Develop capability for LEU target assembly (using KAERI foil).
    4. Develop processing capability, QA/QC, etc.
    5. Transport container
    6. Waste management and environmental controls

Education and Training

- IRT-2000 can serve as a useful platform for nuclear education and training.
- Support nuclear power, science, biology and medicine, radiation protection, and health physics and radioactive waste cleanup.
- If LWR program were to be established, could provide training courses for power plant operator personnel, regulatory staff.

- Relationships need to be established or strengthened with domestic universities having nuclear engineering and science undergraduate and graduate programs.
- Education and training network involving IRT-2000 could also be established with ROK governmental and educational nuclear programs.

Neutron Activation Analysis

- Analytical technique for determination of trace elements in a variety of complex sample matrices.
- Most simple and widely used application of RRs.
- Large number of potential domestic users including mining, environmental, food, medical, archaeology, etc.

  Concrete Example: NAA is used to analyze air particulate, water, soil, waste, human biological, and other samples to determine presence of trace elements or heavy metals in studies on air and industrial pollution, drinking water quality, micronutrients, etc.

Equipment Needs

- Pneumatic sample transfer system (rabbit system) for irradiations.
- Counting equipment (gamma spectrometer – semiconductor device and multi-channel analyzer, approx. $30,000); lead shielding ($10,000), and to improve detection limits Compton suppression spectrometer ($75-100,000)

Personnel and Software

- Several trained persons
- Standard analytical software available from IAEA
- International inter-comparison exercises for proficiency testing

Silicon Transmutation Doping

- Irradiation of ingots (5-15 cm diameter; up to 70cm high) of high purity silicon (better uniformity of crystalline structure) for semiconductors.
- Commercial business - some RRs have specialized silicon irraiation production facilities.
- Possible collaboration with an existing facility that needs additional irradiation capacity or with ROK industrial customers (huge demand in ROK, no STD in ROK).

Facility/Equipment Needs

- Use vertical channels or horizontal beam tubes.
- Need special handling tools, decay storage location, and decontamination facility.
- Miscellaneous equipment

Personnel

- One principle engineer, and a number of technicians required.

Neutron Radiography

- Radiography: produces image on film exposed to secondary radiation when neutrons penetrate specimen (special x-ray).
  Concrete example: inspection of irradiated fuel; observation of the status of oil flow within engines.
- Mature technology, many industrial purposes, low-cost, and simple.
- Professional staff member and technician to routinely operate.
- Probably significant number of potential domestic users for IRT.

Neutron Scattering

- Leading-edge technique using neutrons of different energy levels extracted through horizontal beam ports.
- Neutrons interact with various samples, analysed using sophisticated spectrometers revealing material structure.
- Used for a wide range of experiments from fundamental physics to biological sciences, many RRs implementing the technology.
- Small facilities like IRT-2000 could specialize with one or two instruments (e.g. Small-Angle Neutron Scattering), first gaining experience at an international user center (e.g. Russia, France, Germany)
- Scattering would require a considerable investment ($500,000~) including several well-trained instrument scientists

Nuclear Safety Issues

- Infrastructure activities (conversion, spent fuel removal, I&C upgrade) impact the reactor facility and ancillary systems.
- These activities will require changes, amendments, and updating of the facility Safety Analysis Report (SAR).
- National regulatory procedures, process, and requirements need to be fulfilled.
- International standard is to have an "independent" nuclear safety regulatory body, separate from the authority(ies) responsible for the reactor and other related facilities.
- DPRK should establish an independent nuclear regulatory authority
- New utilization activities (especially RI production, transport, etc) also require safety analysis, review, and authorization.

Safeguards Measures

- Safeguards inspections involve measurement taking via non-destructive analyses of material and placement of seals on containers with nuclear material.
- These measures are carried out when nuclear material is entering or leaving the facility:
  1. fresh LEU fuel is received and placed in core, and

2. Spent fuel is packaged and to be shipped.

- Measures also include activities to detect undeclared Pu production.

Conclusions

- North Korean IRT-2000 (and associated hot cells, isotope, and radiochemical facilities) technically capable of carrying out many applications relevant to social development, science, and energy.
- Strategic and business planning necessary to identify domestic users and international markets and partners.
- Human resources are probably sufficient for a variety of activities, although some re-training will be useful.
- IRT-2000 infrastructure needs attention – comprehensive review is necessary, new (LEU) fuel, modernization (I&C upgrade), spent fuel management (HEU fuel take-back).
- LEU conversion and an isotope production program can use existing North Korean nuclear experts - reactor physics scientists, radiochemical processing technicians, and reactor operations technicians:
    1. 5-10 experts for LEU conversion
    2. 5 experts for I&C upgrade
    3. ~20 experts for spent fuel removal
    4. 200-500 personnel for reactor operations and on-going utilization programs
- LEU conversion will take 2-3 years and cost $1.5-2 million dollars.
- International programs (US/DOE/NNSA/GTRI) can provide funding for return of fresh/spent HEU to Russia, and for replacement LEU fuel and technical assistance with LEU conversion.
- Once converted, IRT-2000, with other DPRK facilities such as Institute for Atomic Energy cyclotron, can produce a variety of isotopes for domestic and international use.
- Mo-99 (for cancer, heart, other diagnosis) has greatest export potential, to ROK, Japan, China and Asia.
- Conversion, isotope production, other applications can benefit from regional and international cooperation, including research reactor coalitions and networks, at every step (as noted in previous slides).
- Such cooperation will provide additional transparency.
- Conversion (and utilization activities) cannot be completed (and implemented) without DPRK:
    1. accepting full-scope safeguards
    2. concluding Additional Protocol (AP) and implementing its obligations (especially due to concerns that the IRT-2000 in the past produced/separated gram quantities of Pu)
- Full-scope safeguards and AP, together with continuous international involvement at the facility, should provide adequate assurance regarding peaceful use.

Relevant Research Reactor Publications

- IAEA TECDOC-1212 “Strategic Planning for Research Reactors,” 2001

- IAEA TECDOC-1234 “The Applications of Research Reactors,” 2001

- IAEA Technical Report Series No. 455 “Utilization Related Design Features of Research Reactors: A Compendium,” 2007