International Atomic Energy Agency Support of Research Reactor Highly Enriched Uranium to Low Enriched Uranium Fuel Conversion Projects

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ABSTRACT
The IAEA has been involved for more than twenty years in supporting international nuclear non-proliferation efforts associated with reducing the amount of highly enriched uranium (HEU) in international commerce. IAEA projects and activities have directly supported the Reduced Enrichment for Research and Test Reactors (RERTR) programme, as well as directly assisted efforts to convert research reactors from HEU to LEU fuel. HEU to LEU fuel conversion projects differ significantly depending on several factors including the design of the reactor and fuel, technical needs of the member state, local nuclear infrastructure, and available resources. To support such diverse endeavours, the IAEA tailors each project to address the relevant constraints. This paper presents the different approaches taken by the IAEA to address the diverse challenges involved in research reactor HEU to LEU fuel conversion projects. Examples of conversion related projects in different Member States are fully detailed.

INTRODUCTION
For more then twenty years the IAEA has been an active partner in international efforts to address non-proliferation challenges associated with the transfer, utilisation and storage of Highly Enriched Uranium (HEU). A significant portion of this support involves the conversion of research reactors from HEU to LEU fuel and radioisotope production targets. The IAEA has applied an array of approaches to facilitate specific conversion endeavours, as well as support the overarching RERTR programme in general. These different approaches permit the IAEA to cater its support to the specific challenges unique to each conversion effort.

Technical Cooperation projects have in the past, and continue to be a means for the IAEA to implement HEU to LEU conversion of research reactors in different member states. However, the approach and scope for each project often differ significantly depending on the individual facility constraints. This paper will detail different approaches taken in support of conversions in Chile, Libya, Poland, Portugal and Romania.

Activities within the IAEA's regular budget programme also support conversion for various families of research reactors. As with the facility-specific conversion endeavours, the approaches are customised to address the relevant needs and challenges. Efforts to convert Miniature Neutron Source Reactors (MNSR) and Accelerator Driven Sub-critical (ADS) systems are presented.

Finally the IAEA remains involved in broader international conversion efforts and activities. Examples of such activities include the Mo-99 production from LEU targets and direct support of international meetings aimed at reducing the use of HEU. Further detail is outlined below.

SUPPORT OF SPECIFIC CONVERSION PROJECTS THROUGH TECHNICAL COOPERATION

The IAEA's Technical Cooperation (TC) programme aims to promote tangible socio-economic impact by contributing directly in a cost effective manner to the achievement of the major sustainable development priorities of each country. TC projects have in the past, and continue to be a means for the IAEA to implement HEU to LEU conversion of research reactors in different member states. The specific mechanisms of the TC programme provide for the development of human resources as well as the procurement of equipment and services to achieve the desired results.

However, the approach and scope for each project often differ significantly depending on the individual facility constraints. Five examples of TC projects that involve recent or ongoing HEU to LEU research reactor conversions include:

- In Chile the IAEA supported the development of a qualified domestic LEU fuel fabrication capability.
- Support to Libya's conversion effort included an assessment of the replacement LEU fuel and implementation of poolside inspections capabilities.
- An ongoing project in Poland involves the complete conversion including the procurement of engineering services and fuel qualification due to the uniqueness of the fuel design.
- In Portugal, qualified fuel is being provided through an IAEA TC project to support conversion.
- In 2006 Romania's 14 MWt TRIGA reactor completed its conversion as TRIGA fuel supply was transitioning from General Atomics in the USA to the Compagnie pour l'Etude et la Réalisation de Combustibles Atomiques (CERCA) facilities in France.

Fuel Fabrication in Chile

The conversion of the RECH-1 Research Reactor in La Reyna, Chile was completed in May 2006 when a full core of 32 LEU fuel elements was loaded into the reactor. This event marked the end of a fuel fabrication programme commenced in 1995. Chilean authorities developed a qualified, domestic LEU fuel manufacturing capability to facilitate their conversion programme.

IAEA support for this effort commenced in 2001 through TC project CHI/4/021. The objective of CHI/4/021 was to qualify the irradiation performance of fuel fabricated in Chile; to ensure quality control and assurance of silicide fuel, and to improve fuel fabrication technology. The scope of the IAEA project included equipment and services as well as human resource development in support of an irradiation and post irradiation qualification programme conducted at the Nuclear Research and consultancy Group (NRG) High Flux Reactor (HFR) facilities in Petten, the Netherlands.

Libya Arab Jamahiriya

Conversion of the research reactor cores (10 MW and Critical Facility) in Tajoura, Libyan Arab Jamahiriya has been performed under a direct government to government agreement and not as a specific IAEA conversion project. Nevertheless, the government of the Libyan Arab Jamahiriya has requested assistance from the IAEA for: i) assessment of the quality of the proposed LEU IRT-4M replacement fuel, and ii) implementation of poolside inspection capabilities at Tajoura.

The Agency appointed an appropriate independent fuel expert to help the Libyan counterpart in evaluating quality assurance and quality control aspects of LEU fuel at the fabrication plant. The IAEA also assisted in selecting and purchasing special poolside inspection equipment to be used to closely control LEU fuel behaviour during irradiation. The latter includes an underwater visual inspection device, a sipping test facility and a specifically designed endoscope system that allows visual inspection of the fuel surface within the narrow gaps between the fuel tubes. The IAEA

also organized an expert mission to Libya to assist in installing and starting up these new devices and in training the Libyan operating staff at the site.

Poland's MARIA research reactor

The MARIA reactor, operated by the Polish Institute of Atomic Energy (IAE), is a Russian-designed RR that operates with Russian-supplied HEU fuel. The reactor initially operated with 80% enriched HEU and converted to 36% HEU in 1999. The present objective is to convert the current core to LEU fuel under the IAEA technical cooperation project POL/4/017.

Recently, IAE has been studying the possibility of using fully qualified LEU silicide fuel to convert the MARIA reactor. The proposed silicide fuel (U3Si2) with a density of 4.8 g/cm3 has been qualified to very high burnups and there is extensive experience with its use in many research reactors worldwide. However, the assembly design proposed for use in MARIA is unique and must be qualified for the MARIA operating conditions by irradiating two lead test assemblies in the MARIA reactor. POL/4/017 has been approved by the IAEA to support the conversion to LEU fuel.

The IAEA organized an expert mission to Poland to assist in developing design specifications and drawings necessary for the procurement of the LEU fuel, initiated a tender process to procure LEU fuel and convened and independent international expert consultation for technical evaluation of tenders for LEU fuel supply (June 2006). At the time of writing the selection of the preferred tender is finalized and a contract is being negotiated. It is worth mentioning here that, the procurement of the LEU fuel will be carried out in 2 discrete phases:

Phase I scope includes research, engineering and design services for the development of quality assurance programs and the finalization and verification of the mechanical design of the fuel assemblies and all necessary drawings and mechanical specifications, including technical inspection documentation. The design scope will end with the supply of two (2) dummy assemblies for hydraulic testing. After the dummy assemblies are accepted, LEU Lead Test Assemblies (LTA), with Low Enrichment (E<20%), meeting pertinent specifications and drawings will be supplied. Satisfactory demonstration of correct irradiation behaviour in the Maria RR of these two LTAs is a mandatory condition to qualify the fabricator for the supply of fuel assemblies necessary for the conversion of the Maria core.

Phase II involves purchasing the number of LEU fuel assemblies necessary for conversion of Maria RR. This step is conditional on the successful completion of the LTA qualification irradiation as mentioned above. In connection with this project, the IAEA will organize auditing missions to the supplier's factory to assess quality of fuel fabrication.

Portuguese Research Reactor

Conversion of the Portuguese reactor has been carried out under TC project: POR/4/016 "Core Conversion of the Portuguese Research Reactor to LEU" The objectives of the project are: to convert the present HEU fuel core of the Portuguese Research Reactor (RPI) to LEU fuel and return the HEU spent fuel to the USA within the framework of an agreement signed by Portugal and the US Department of Energy (DOE) under the FRRSNF Acceptance Programme.

The IAEA issued a call for tenders for LEU fuel, convened an independent international expert consultancy meeting to evaluate the offers and selected the preferred tender. In January 2007 an independent fuel inspection was completed at the manufacturer's facilities. As of this writing, the LEU fuel has been delivered to the facility per a tripartite contract between RPI, Compagnie pour l'Etude et la Réalisation de Combustibles Atomiques (CERCA), and the IAEA.

A more complete description of this project is reported in [3]

Romania's 14MW TRIGA research reactor

The TC National Project ROM/4/024 to complete the conversion of the 14 MW TRIGA-reactor in Pitesti, Romania became fully operational in 2003. A contract to supply the fresh LEU fuel was signed between the IAEA, representatives of the Romanian government (RAAN/Research Institute Pitesti & Regulatory Authority CNCAN), and a representative of Compagnie pour l'Etude et la Réalisation de Combustibles Atomiques (CERCA)/TRIGA International in early November 2003.

It is important to note that during the implementation of this project, fuel supply operations were transitioning from General Atomics to the CERCA facilities in France. This challenge was adequately managed by CERCA with no adverse impact on the project cost, schedule or quality.

Under this contract, IAEA officials together with officials from CNCAN and the Institute for Nuclear Research (ICN), Pitesti, jointly carried out:

- A Quality Assurance audit of the TRIGA manufacturing line at the CERCA facility in Romans, France from 22 to 24 January 2004;
- An acceptance inspection at the CERCA facility of the first 50 rods (two complete assemblies) of fuel fabricated, prior to their shipment to Pitesti, from 26 to 29 October 2004;
- An acceptance inspection at the CERCA facility of the second 175 rods (seven complete assemblies) of fuel fabricated, prior to their shipment to Pitesti, from 3 to 5 October 2005; and
- An acceptance inspection at the CERCA facility of the final lot of 179 TRIGA fuel assemblies (175 specified in the original contract plus 4 spare rods agreed to be supplied in a supplemental contract) from 15- 17 March 2006.

The final lot of LEU fuel was delivered to Pitesti on March 30, 2006 and the fuel was loaded into the TRIGA reactor by mid-May 2006, at which time the full-core conversion of the TRIGA was completed. The last irradiated HEU fuel elements were removed from the TRIGA prior to May 12, 2006 and after several years of cooling, this U.S.-origin HEU will be shipped to the US under the FRRSF Acceptance Programme.

REGULAR PROGRAMME ACTIVITIES

Activities coordinated within the Regular Programme and Budget (P&B) support the IAEA Medium Term Strategy (MTS). Specific activities support broader outputs and outcomes. HEU to LEU conversion of specific facilities are examples of outputs that contribute to the general reduction of HEU utilization – a strategic outcome. IAEA P&B efforts include support for the conversion of various families of research reactors. As with the facility-specific conversion endeavours, the approaches are customised to address the relevant needs and challenges. Efforts to convert Miniature Neutron Source Reactors (MNSR) and Accelerator Driven Sub-critical (ADS) systems are presented.

Miniature Neutron Source Reactors (MNSR)

The Chinese-built Miniature Neutron Source (MNSR, 27 kW) reactors (four in China, five abroad) are low-power, neutron source research reactors used primarily for neutron activation analysis, education, and training. These reactors have cores consisting of about 1 kilogram of HEU, enriched to 90% or greater. The IAEA initiated a Coordinated Research Project (CRP) in June 2006 to assist in the conversion of these reactors to LEU fuel with objectives:

- To assist institutions in Member States with MNSR reactors with HEU cores to convert to LEU fuel with minimal reduction of the utilization capacity of the reactors;
- To establish a common approach for the conversion to LEU of the existing MNSR reactors through a comparative analysis of the feasibility of conversion;
- To provide the basis for individual MNSR reactors to safely convert to qualified LEU fuel;
- To carry out calculations and conduct studies necessary to plan and implement MNSR conversion to LEU; and
- To disseminate information on the various technical and other steps necessary to safely convert MNSR reactors to LEU fuel.

Institutions in China (3), Ghana, Iran, Nigeria, Pakistan, and Syria are participating as contract holders in this CRP. The U.S. (Argonne National Laboratory) is an agreement holder.

At the end of the CRP, it is expected that all of the participants will have acquired an appropriate understanding of the technical and other steps necessary as well as the documentation that will be required in order to meet national regulatory requirements to carry out the conversion of their HEU-fuelled MNSR reactors to LEU cores. Information acquired through the CRP will be published by the Agency in the form of a technical publication that will serve as an addendum to the IAEA's existing core conversion handbook.

The first Research Coordination Meeting (RCM) of this CRP was held in Vienna, Austria from 11 to 14 December 2006 [4]. At this meeting the countries participating in the RCM stated that although most of their reactors have substantial remaining lifetimes for their HEU cores and have no pressing operational need to re-fuel, they are committed to converting to LEU when conversion studies are complete and an LEU fuel is available, as long as external resources are available to cover the costs of conversion. A complete Workplan in included in the meeting report [4].

Accelerator Driven Subcritical Assembly Systems

An Accelerator Driven Subcritical Assembly System (ADS) is composed of a subcritical assembly and an accelerator. In such a system, the accelerator provides a charged particle beam for generating a neutron source to drive the subcritical assembly. The subcritical assembly consists of an array of nuclear fuel elements without the possibility of sustaining a nuclear chain reaction. In such subcritical assemblies the neutrons are produced by the interaction of the charged particles with the target materials and multiplied in the fuel materials. Differently from traditional reactors, that need devices with absorbing material to stop the nuclear reactions, on an ADS the nuclear reaction can be stopped by just switching off the charged particle beam. Because it is foreseen that they can utilize actinides and transmute long lived fission products while producing energy, ADS systems have attracted increasing worldwide attention, and at present, there are more than twenty IAEA Member States with ADS activities. Some of them are already operating or have plans to construct ADS systems.

In principle, the fuel in the subcritical assembly can be HEU or LEU. In 2005, to address increasing non proliferation concerns related to the civilian uses of HEU and responding to a recommendation of the 2004 RERTR international meeting, the IAEA organized a Technical Meeting to exchange information and further discuss this issue. The meeting was held in Vienna from 10 to 12 October 2005, and was attended by 15 experts from 13 Member States. Its main purpose was to explore the technical feasibility of using LEU as an alternative fuel material for the subcritical assembly component of ADS systems. At the meeting, participants presented

reports describing status and current plans of their ADS projects, including objectives, applications, main characteristics and design details of the subcritical assemblies.

During the meeting it was confirmed that some facilities are already using HEU in their operational ADS systems and others are considering the use of HEU in their planned projects. One major recommendation from the Technical Meeting was for the IAEA to organize and coordinate activities with interested scientific organizations to study the utilization of LEU in ADS systems.

In response to the above mentioned recommendation the IAEA initiated a new collaborative activity with the purpose of studying the feasibility of using LEU in ADS systems. A kick off workshop for this new undertaking was held in Vienna from 6 to 9 November 2006 [5]. The meeting enabled researchers from recognized scientific organizations to exchange information and design an international collaborative activity to span the 2007-08 biennium, specifically focused on the use of LEU in ADS systems. During the workshop the participants presented their projects and capabilities, and determined the scope and time schedule of the new collaborative activity. Responsibilities to conduct specific work within this undertaking were also assigned at the meeting.

Among others, the workshop covered the following topics:

- National experience on ADS related activities;
- Available infrastructure for ADS experiments;
- Available infrastructure for ADS calculation, including details of codes;
- Proposed participant work under the new collaborative activity;
- Availability of human resources ; and
- A time schedule, with well defined milestones.

Since this meeting research contracts have been signed with researchers from Argentina, Belarus, Brazil, China, India, Korea, Poland, Serbia and Ukraine.

MOLYBDENUM-99

Technetium 99m, the daughter product of Molybdenum 99 (Mo-99) is used for approximately 20-25 million medical diagnostic procedures worldwide. Several commercial entities produce Mo-99 by irradiating HEU targets and recovering Mo-99 in dedicated processing facilities. In line with efforts to minimize and eventually eliminate the use of HEU in civil commerce, efforts are underway to shift the production of medical isotopes away from the use of HEU.

The IAEA initiated in 2005 a Coordinated Research Project (CRP) on “Developing techniques for small-scale indigenous production of Mo-99 using LEU or neutron activation.” The objectives of this CRP are to:

- Assist Member States with the adoption of LEU-modified Cintichem (foil targets) or neutron activation (gel moly) technology for producing Mo-99,
- Further demonstrate efficacy of LEU and neutron activation production of Mo-99,
- Foster capacity building for local/regional self-sufficiency to meet Mo-99 needs,
- Advance international non-proliferation and nuclear security objectives, while promoting sustainable development and the sustainability of nuclear research institutes.

The first Research Coordination Meeting (RCM) was held 6-9 December 2005, which reviewed, revised, and finalized individual country work plans, established a set of coordinated activities for

both fission and gel moly groups, specified the material and expert assistance requirement, and agreed on a list of action items with dates/milestones.

The second RCM was held 16-20 April 2007 in Bucharest, Romania [6]. The RCM reviewed the status/progress of each CRP participant's activities; reviewed domestic nuclear medicine plans and Mo-99 requirements, to determine production targets; reviewed constraints, needs, and arrangements for supply/technical assistance; improved understanding to finalize target analyses; outlined requirements for current Good Manufacturing Practices (cGMP); and updated the work plan. Activities planned for 2007 – early 2008 include provision of LEU foils from Korean Atomic Energy Research Institute, completion of safety documentation, facility preparations, and initial test irradiation of foils.

CONVERSION RELATED MEETINGS AND WORKSHOPS

The "Technical Workshop on HEU Minimization", held on 17-18 June 2006, as well as the "International Symposium on Minimization of HEU in the Civilian Nuclear Sector", which followed the technical workshop on 19-20 June, were organized by the Government of Norway in cooperation with the IAEA. More than 100 experts from 41 countries participated in the Technical Workshop and around 130 participants from 45 countries in the International Symposium.

Participants in the Technical Workshop concluded that virtually all RRs can use LEU fuel without a significant penalty to their educational, scientific, technical, and industrial applications. Several presentations made by users of reactors that have already converted to LEU clearly demonstrated that any "flux penalty" that resulted from the conversion can be managed and compensated by other measures so as not to affect the performance of the reactor.

There was broad consensus that the production of Mo-99 from LEU is technically feasible, and that future new producers of Mo-99 should do so from LEU only. There was also consensus that the only significant obstacles to conversion to LEU of the present major Mo-99 production facilities are economic, financial, and political. It was agreed that the RERTR programme and the related research reactor spent fuel "take-back" programmes have made significant progress in HEU minimization, and that there is substantial and successful international collaboration in this area. The workshop called for these efforts to be enhanced and expanded on the basis of voluntary decisions by states interested in converting reactors or shipping spent fuel. The positive role of the IAEA in these efforts was highlighted, and there was broad consensus that the IAEA should expand its relevant activities, including the promotion of cooperation between and international sharing of RR facilities.

The International Symposium was marked by broad political discussions placing this subject within the context of the global nuclear disarmament debate, especially regarding the differing obligations of Nuclear Weapons States and Non-Nuclear Weapons States under the Nuclear Non Proliferation Treaty (NPT). A number of representatives stressed that actions to minimize HEU should not impinge upon the rights to develop peaceful uses of nuclear energy under Article IV of the NPT. However, there was consensus that activities related to the minimization of HEU in the civil sector should proceed on the basis of voluntary requests by national authorities, in the context of available donor funding and international technical assistance.

CONCLUSION

The IAEA continues contributing to international HEU to LEU conversion efforts and general HEU minimization by supporting RERTR. Important progress has been achieved in the period

2005-2007 in the expanded set of new HEU minimization activities initiated in 2005. These efforts will be maintained, strengthened and expanded in the coming years.

To assist Member States and the international initiatives in their efforts to reduce and eventually eliminate the use of HEU, the Agency has utilized and continues to offer a broad array of mechanisms available through its Regular Agency Programme and Technical Cooperation Programme.

The IAEA encourages Member States to contact pertinent departments at the Agency to seek assistance and make suggestions for new activities in relation with RR and target conversion issues.

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