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Working materials Consultancy on

Conversion Planning for Mo-99 Production Facilities from HEU to LEU

(10CT11937)

Organized by

International Atomic Energy Agency, Vienna, Austria

> 24 – 27 August 2010 IAEA Headquarters, Vienna, Austria

NOTE

The views expressed remain the responsibility of the named participants and do not necessarily reflect those of the government(s) of the designating Member State(s). In particular, neither the IAEA nor any other organization or body sponsoring the meeting can be held responsible for this material.

FOREWORD

Technetium 99m (Tc-99m), the daughter product of Molybdenum 99 (Mo-99), is the most commonly utilized medical radioisotope in the world, used for well over 30 million medical diagnostic procedures annually and comprising some 80% of all diagnostic nuclear medicine procedures. Until 2010, approximately 95% of Mo-99 consumed worldwide is produced in research, test or isotope production reactors by irradiation of Highly Enriched Uranium (HEU) targets that are subsequently processed primarily to recover Mo-99. There are mainly four large-scale commercial processors of Mo-99 (i.e. 1000 6-day curie or more per week), three of them utilizing HEU targets and dedicated processing facilities, while a fourth, (NTP/SAFARI-1, South Africa) is converting its process to Low Enriched Uranium (LEU) and a fifth producer (OPAL, ANSTO, Australia) is expanding current LEU-based production.

In line with the international objective of minimizing and eventually eliminating the use of HEU in civil commerce, national and international efforts have been underway to shift the production of medical isotopes from HEU to LEU targets. A small but growing amount of the current global Mo-99 production is derived from the irradiation of LEU targets. CNEA Argentina successfully converted its small-scale Mo-99 production to LEU and has been routinely producing for several years. BATAN, Indonesia has converted Mo-99 production to LEU, based on foil targets and the LEU-Modified Cintichem process with assistance from Argonne National Laboratory, USA. New LEU-based Mo-99 commercial-scale production facilities have been constructed by INVAP, S.A. (Argentina) based on CNEA targets and processing methods at OPAL (mentioned above) and at the ETRR-2 research reactor in Egypt (currently in commissioning phase).

The Minimisation of Highly Enriched Uranium (HEU) in the Civilian Nuclear Sector Symposium, Oslo, Norway, 17-20 June, 2006 suggested, "The production of medical and other isotopes using LEU targets should to the extent possible be encouraged, taking into account technical and economic considerations." The Global Initiative to Combat Nuclear Terrorism, Workshop on the Production of Mo-99 Using Low Enriched Uranium, held in Sydney, Australia, 2-5 December 2007, and the U.S. National Academy of Science 2009 study (NAS study) "Medical Isotope Production without Highly Enriched Uranium" both concluded that production of Mo-99 from LEU targets has been technically demonstrated, and that any new Mo-99 production facilities should be based on LEU. They also stated that conversion of existing Mo-99 facilities is technically feasible, although certain technical and financial/economic issues will have to be addressed. The NAS study also concluded that "LEU targets that could be used for large-scale production of Mo-99 have been developed and demonstrated" and "...the committee sees no technical reasons that adequate quantities cannot be produced from LEU targets in the future." Furthermore, during the April 2010 Nuclear Security Summit, Participating States agreed to collaborate "... to research and develop new technologies that require neither highly enriched uranium fuels for reactor operation nor highly enriched uranium targets for producing medical or other isotopes, and will encourage the use of low enriched uranium and other proliferation-resistant technologies and fuels in various commercial applications such as isotope production;" and "...will provide assistance to those States requesting assistance to secure, account for, consolidate, and convert nuclear materials".

Recent unplanned outages of ageing, isotope production reactors and processing facilities led to serious Mo-99 supply disruptions. In view of the crisis situation prevailing since the end of 2007, international efforts focused on immediate, interim, and longer-term options to address the isotope supply reliability. Major ongoing repairs are expected to be completed during the third quarter 2010 at two reactors, easing the immediate supply concerns. Following their return

to service, a shift in focus, back to addressing long-term sustainability aspects including HEU to LEU conversion, is deemed necessary.

As part of the IAEA's continuing involvement to address the interim- to long-term shortages in Mo-99 supplies, including in cooperation with the High-Level Group on the security of supply of Medical Radioisotopes (HLG-MR) convened by OECD/NEA, the Agency convened this Consultancy to identify and help develop a plan to address the technical and related issues associated with conversion of existing isotope production facilities to LEU-based production. The major technical concerns associated with conversion are: (1) a target design that will allow five-times more uranium in the same geometry as the current HEU target (therefore require no additional irradiation positions in the reactor and no additional targets to be processed), and (2) integrating this new target into current HEU-based processes with minimum modification to the process with the same or higher yield and purity as current target and process combinations. Means to lower liquid and gaseous radioactive-waste generation were also considered. The meeting established a nominal "roadmap" of the activities that need to be carried out in order to accomplish such conversions, as a basis for further activities, and defined related schedule and cost-related issues. The US-NAS study report released in January 2009, as well as the work of the HLG-MR and parallel IAEA activities, was an important source of relevant background information.

CONTENTS

F	OREWORD	
C	ONTENTS	
1.	EXECUTIVE SUMMARY	5
2.	OBJECTIVES	6
3.	CONSULTANT DISCUSSIONS	6
	3.1. Assumptions	6
	3.2. Challenges / Barriers	
	3.3. Opportunities for collaboration	
	3.4. Processing front-end	
	3.5 Waste Treatment, disposal, recycle	
4.	RECOMMENDATIONS	13
5.	AGREED ACTIONS	13
	5.1. ANL/G. Vandegrift	13
	5.2. B&W/Y-12/L. Jollay	
	5.3. Covidien/L. Barbosa	
	5.4. GSG/H-J Roegler	
	5.5. IAEA/E. Bradley	
	5.6. INR/C. Toma.	
	5.7. IRE/D. Moyaux	
	5.8. NIIAR/ R. Kuznetsov	
	5.9. NTP/G. Ball	15
	5.10. Sameh, A. A.	
	5.11. University of Missouri/C. Allen	
6.	SUMMARY OF PRESENTATION	16
	6.1. P. Staples (USA – DOE/NNSA)	16
	6.2. A. Sameh (Independent expert, Germany)	
	6.3. G. Beyer (GSG, Germany/France)	
	6.4. G. Vandegrift (ANL, USA)	
	6.5. C. Allen, (University of Missouri, USA) and L. Jollay (B&W/Y-12, USA)	
	6.6. G. Ball, (NTP, South Africa)	
	6.7. B. Briyatmoko (BATAN, Indonesia)	
	6.8. R. Cameron (OEDC/NEA)	
	6.9. M. Stewart (ANSTO, Australia)	
	6.10. R. Kuznetsov (NIIAR, Russian Federation)	
	6.11. CK. Kim (KAERI, Republic of Korea)	
	6.12. C. Toma (INR, Romania)	
	ANNEXESANNEX 1 - Tentative Agenda	
	ANNEX 1 - Tentative Agenda	
	ANNEX 2 – List of participants	

1. EXECUTIVE SUMMARY

An IAEA Consultancy (CT) on Conversion Planning for Mo-99 Production Facilities from HEU to LEU was held in the IAEA HQ, Vienna from 24 through 27 August 2010. The objectives of the CT were:

- (i) To identify and establish the major aspects and issues that need to be addressed and to define the critical pathway elements/milestones for the conversion of existing Mo-99 production facilities from HEU to Low-Enriched Uranium (LEU)-based production.
- (ii) Assuming an ongoing IAEA role is clearly identified, to formulate a comprehensive proposal for an IAEA activity to progress the defined scope of work.

A series of presentations on relevant experience or ongoing activities were provided by a group of international experts. The following were main points identified during the discussions and/or agreed path forward:

- While there are no insurmountable technical barriers to conversion and growing political alignment / pressure to transition away from HEU, the economic justification for different HEU to LEU conversion projects remains uncertain. The current situation of the global Mo-99 supply chain / market contributes to this uncertainty. However, technology developments in certain key areas, specifically that permit the use of high density, LEU targets by current producers, has the potential to improve the business case of conversion.
- The creation of an International Working Group to support the conversion of Mo-99 production away from HEU. IAEA will organize/host periodic meetings of the group and provide related support as in international collaborative activity.
- Three technical areas were identified for multilateral collaboration:
 - High density, LEU target technology development, proof/testing and commercial availability
 - Front-end, adaptive technology development
 - Back-end technology assessments that consider the ultimate disposition of all solid, liquid and gaseous waste streams and well as opportunities to recycle uranium waste.
- The major producers requested target and front-end technology packages that have been developed and demonstrated in prototypical processing arrangements. They will then make custom modifications as necessary to accommodate their specific needs while protecting their intellectual property.

2. OBJECTIVES

The overall objective of this CT on "Conversion Planning for Mo-99 Production Facilities from HEU to LEU" is to provide a forum for the exchange of ideas, to consider challenges and discuss other constraints faced by commercial companies directly involved in the chemical processing of uranium targets for the production of Mo-99. The meeting aimed to assemble international experts, with demonstrated capabilities directly relevant to the producers' considerations to convert production facilities away from highly enriched uranium (HEU) to low enriched uranium (LEU). The agenda (attached in Annex 1) was developed to facilitate the sharing of experiences, encourage brainstorming discussions and to permit the processors themselves to drive the development of specific recommendations as well as the identification of specific needs. Specific objectives identified in the CT Terms of Reference include:

- To identify and establish the major aspects and issues that need to be addressed and to define the critical pathway elements/milestones for the conversion of existing Mo-99 production facilities from HEU to LEU-based production.
- Assuming an ongoing IAEA role is clearly identified, to formulate a comprehensive proposal for an IAEA activity to progress the defined scope of work.

3. CONSULTANT DISCUSSIONS

Presentations from select participants were given throughout the first day of the CT and into the second. Summaries of each presentation are included later in this report. More detailed discussions aligned with the CT objectives followed the presentations. Additional presentations, not listed in the agenda, were provided on the final day to take advantage of available time. In addition – and consistent with the agenda – a working meeting to advance the development of a high-density uranium foil target was accommodated at the end of the second day. This breakout meeting was led by participants from the University of Missouri (USA), Argonne National Laboratory (USA), B&W/Y-12 (USA) and INR - Pitesti TRIGA reactor (Romania).

3.1. Assumptions

During the discussions, a number of assumptions were captured which help to put the individual conversion endeavours (as well as the remainder of the CT's discussions and this report) in context. These include:

- The final outcome of an HEU to LEU conversion project should be an improvement on the current situation (to compensate for the cost of conversion, perhaps similar to reactor fuel conversion considerations)
- Producers want minimal changes to current processes (unless significant benefits will be achieved)
- The transition away from HEU will occur in the coming years due to global, political alignment; national and international commitments; and the resulting political pressure

3.2. Challenges / Barriers

Conversion projects must overcome a number of challenges. An attempt has been made to categorize the identified challenges; but nearly all will be more easily and/or efficiently managed through technology development and cooperation (either multilateral or bilateral). It

must be noted that any identified technical challenges are not barriers to conversion per se, but rather denote specific areas where technology development could result in improved economic justification for conversion projects. Discussions during the CT produced the following:

Economic

More (approximately 4.7 times) total uranium per Ci of Mo produced will result from the use of LEU targets. This is a particular challenge to the interim storage of process waste due to limited existing storage volume. Opportunities to recycle should be assessed and could include the consideration of a final disposition path for existing HEU waste through down-blending to LEU to support production in a converted facility.

The uncertainty of the cost per delivered target challenges the development of a robust business case to support conversion. The cost of 1 kg of HEU and LEU was considered. Based on input from B&W/Y-12 during the CT, the per-kg costs, including uranium and handling, are approximately \$14,700/kg for LEU and \$62,900/kg for HEU. These costs are, however not all-inclusive. They do not, for example, include the cost of container hire, which in some cases is significant. Low density, LEU targets are currently available from commercial suppliers, but high-density, LEU target designs are not yet commercially available. Experiences from research reactor (RR) fuel reflect an increase in cost by a factor of ~1.3 for dispersion technology.

ACTION B&W/Y-12: Additional information on target supply costs to be provided November (report).

The cost / resource burden required to assess changes (even small ones) to the existing processing technology must be considered.

The Mo-99/Tc-99m market failure, as outlined by the OECD/NEA HLG-MR, challenges the ability of producers to develop a sound conversion business case.

Planning, logistics and implementation

While implementing any modifications (which may include partial D&D) of existing facilities and in particular the hot cells, the need to maintain production, with adequate backup/reserve capacity, must be considered. If parallel production facilities are not available, the risk associated with removing production capacity from service must be thoroughly assessed and minimized to the extent practical.

The costs to establish a parallel production line, or a new line, must be weighed against the risks associated with the loss of production capacity.

Technical

Producers lack proven, commercially available, high density, LEU target designs that can be incorporated into the existing processes in a way that satisfies the aforementioned assumptions. Related to this is the absence of experience in the qualification, or a defined and agreed process to qualify high density uranium targets (including the development of a baseline safety case).

Technology changes including new target designs as well as any adaptive, front-end processing technology must also consider the recovery of desirable isotopes, other than Mo-99, and at the required (i.e. current) activity levels.

Risks of hot-cell contamination with new target designs were also discussed, particularly if the uranium 'meat' is removed from the target prior to insertion into the dissolver.

Regulatory issues

IRE reported regulatory requirements to cut gaseous emissions by 80% as part of their conversion project.

Covidien reported that their license includes a provision to process a given number of targets. Therefore completing a conversion project which would require the irradiation of more targets to achieve the same quantity of Mo-99 could require a license amendment.

Cutting open a target and handling naked foil in a hot cell may not be acceptable to certain regulatory bodies. Mr A. Sameh reported this practice would be unacceptable in Europe.

3.3. Opportunities for collaboration

Participants identified three principal areas for multilateral cooperation (Figure 1): target technology development and qualification (including the development of a baseline safety case); developing demonstration level, adaptive, front-end processing technology linked to a specific target design and existing chemical processing technology; and back-end technology assessments that consider the ultimate disposition of all solid, liquid and gaseous waste streams as well as opportunities to recycle uranium waste.

High-density target qualification / safety case

High density target development and commercial availability would support the economic case for Mo-99 production conversion projects. At a uranium density of approximately 6g/cm³, LEU targets achieve the same ²³⁵U mass loading as HEU dispersion targets that are commercially available today. Two target designs were discussed in detail during the CT: a U-foil design and a U₃Si₂ design. The U-foil design, developed by Argonne National Laboratory, has been manufactured and successfully irradiated in a number of facilities worldwide; but is not currently commercially available nor has it been licensed for irradiation or processing in any of the major Mo-99 producing countries. A U₃Si₂ based target design was developed in Karlsruhe, Germany and considered for use in the Covidien facilities in the Netherlands. U-targets of this design are also not currently commercially available, nor has licensing approval been granted to irradiate or process such targets in any of the major Mo-99 producing countries.

A project involving the University of Missouri (USA), Argonne National Laboratory (USA), B&W/Y-12 (USA) and INR (Romania) is working to develop a baseline safety case from detailed demonstration irradiations of foil targets in Romania. In the process of this work, a bounding, Mo-99, irradiation, qualification set of criteria will be developed from which the foil irradiation and inspection program will evolve. It is anticipated that this protocol will be generically applicable to efforts to qualify other high-density uranium targets as well. A list of bounding criteria was presented and partially developed during the CT. It may be found below.

ACTION Covidien, IRE, NTP, NIIAR, INR: • Work with target irradiation partners to finalize the list of bounding target qualification criteria and confirm / revise all bounding limits/acceptance criteria.

Comments from the processors noted that any target would have to be licensed for irradiation as well as processing. Other, non-technical details must also be considered in any target design and are noted below.

ACTION University of Missouri / Argonne National Laboratory: Confirm if the scope of the baseline safety case will include licensing constraints within processing facilities.

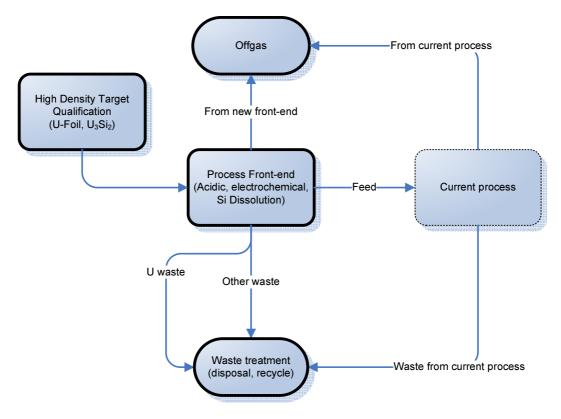


Figure 1 – Topical areas for potential cooperation (dark borders)

BOUNDING CRITERIA - IRRADIATION

- Maximum thermal flux (< 3.E14 n/cm²)
- Max. irradiation time (< 200 hrs)
- % ²³⁵U burnup (< 8%)
- Target heat flux ((W/cm²)
- Target temp (surface and centre of fuel meat)
- Containment "free" volume (m³)
- Depth (from pool surface) at which targets are irradiated (> 7 m, 23 ft.)
- Target cooling period prior to transport (< 12 hrs)
- Current transport cask shielding design: total fission product activity at time of target transport
- Transport / handling constraints (e.g. heat load of cask)
- Grams (or mols) of noble gases (Kr & Xe) generated during target irradiation
- Ideal target dimensions (i.e., size) and LEU-foil mass
- Ideal LEU-foil (meat) thickness (125 μ m [5 mils] 180 μ m [7 mils]); specific target power (W/gU) increases with decreasing foil thickness (\sim 5% per 25 μ m Δ)

BOUNDING CRITERIA – PROCESSING

- Gas release during processing
- Demonstrated surface contamination of an irradiated, naked foil
- General contamination (e.g. of activated aluminum)
- Other processing related constraints

OTHER ASPECTS OF TARGET DESIGN

- Cost and accessibility of supply
- Preferred target geometry (annular, plate)
- Preferred cladding material

Mr A. Sameh shared a CERCA report on the development of U₃Si₂ research reactor fuel at a density up to 6 g/cm³ and explained the experiences of related work in Karlsruhe which also involved a processing front-end. As already mentioned, U₃Si₂ targets are not commercially available and while efforts to develop research reactor fuel at the required uranium density (6 g/cm³) were unsuccessful, participants were confident Mo-99 targets could be developed due to the significantly lower burn-up requirements for targets as compared to fuel.

The representative from BATAN (Indonesia) noted their organization currently manufactures research reactor fuel elements from U₃Si₂ at a uranium density of 5.2 g/cm³.

ACTION GSG/H-J Roegler: Obtain additional information from CERCA regarding the irradiation of 6 g/cm³ U₃Si₂ targets.

During the final day of the CT a more detailed breakout discussion was conducted on the specific requirements and planning related to target R&D. A number of specific actions were agreed and are listed below.

ACTION ANL, B&W/Y-12, INR, University of Missouri: Define a detailed LEU-Foil target test plan and distribute to producers & KAERI in time for a detailed review during the RERTR (October 10-14).

ACTION ANL/G. Vandegrift: Gather information related to U₃Si₂ target development.

ACTION Covidien, INR, IRE, NIIAR, and NTP: Review U₃Si₂ information and recommend a path forward to the Working Group.

A short discussion was also held with R. Kuznetsov of NIIAR regarding any opportunities to accelerate the conversion of the NIIAR project to LEU (i.e. the project is currently installing GSG technology, so – for example – if a high density, LEU target can be deployed with demonstrated adaptive technology for the GSG process, might there be interest to deploy it in Russia?).

ACTION NIIAR/R. Kuznetsov: Discuss the potential for international collaboration to accelerate the current plans to convert Mo-99 production to LEU with NIIAR staff and communicate any opportunities back to the Working Group/IAEA.

3.4. Processing front-end

The introduction of an alternate target design will require modifications of current Mo-99 processing technology. Currently this technology is intellectual property, closely guarded by all major producers. However, representatives of the major producers agreed during the CT that their efforts to convert would benefit from collaborative R&D efforts to develop and provide technology packages (i.e. a combination of a target design with an adaptive chemical processing front-end) for their consideration and further development / integration with current processing technology. A complete package would include all target information from the section above – including the baseline safety case as well as all design details of the adaptive front-end processing with details on the makeup of the feed and all waste streams (see Figure 1) based on demonstration trials of the technology combinations.

Similar to the discussion of high density target technologies, work on front end process technology is being pursued (or has been completed in the past). Neither has long term, large-scale (1,000s of Ci/week) operating experience, nor is either currently licensed for operation. Processing technology relevant to current alkaline based processes and a U₃Si₂ target was presented by Mr A. Sameh. Similarly, ANL is progressing 2 different adaptive technologies for the consideration of the alkaline processors and the use of a metallic U-foil target. Mr G. Vandegrift noted ANL's interest in available hot cell / facility capacity to progress larger scale demonstration work.

Mr G. Ball discussed NTP's first phase of their conversion effort from 45% enriched uranium, relying on LEU dispersion targets and some resulting processing modifications – the details of which are considered business-confidential by NTP (see the summary of the NTP project in the presentation section below). Mr P Cristini (CNEA) noted that CNEA may have some relevant experience to share as well from efforts to convert Mo-99 production in Argentina.

ACTION ANL: Status of work to date (RERTR conf. G. Vandegrift to forward publications)

ACTION A. Sameh: Provide a list of publications detailing the work completed at Karlsruhe as well as the relevant patent or patents.

ACTION IAEA: Collect and distribute technology packages as discrete and complete sets of information in lieu of a piecemeal / document by document approach. Consider a website as an information store.

3.5 Waste Treatment, disposal, recycle

CT participants discussed the necessity to thoroughly evaluate the complete waste management burden of different target and processing options as those technologies are developed. Waste stream descriptions (characterization) will be a required component of the target and front-end adaptive processing technology development work (the technology packages) to permit their thorough assessment by the major processors. The characterizations should include a breakdown and note any mixed waste (vs. radiation/activated waste only). Participants cited the value of being made aware of local constraints / regulations on the relevant waste streams (to optimize the technology development). The major producers are best positioned to provide this information.

ACTION Covidien, INR, IRE, NIIAR, and NTP: Provide summary reports of all waste stream limits, regulations and any other relevant constraints.

ACTION Covidien: Inform IAEA of ownership of waste after transfer to COVRA.

Action IAEA: Collect and distribute waste stream summary reports.

Participants agreed that detailed discussions regarding specific waste management solutions can not proceed until the target and processing technologies become better defined. However it was generally agreed that in parallel with that development, cost/benefit and technical feasibility assessments should be progressed to consider

- uranium recycling
 - o responsible organization
 - o completed locally, regionally, or by some other means
- options to store/decay wastes
- disposal
- o treat/condition
 - options
 - technology
 - waste form
- o volumes,
- o waste acceptance criteria.

As the waste management options are developed, they should also be considered as to their applicability to current or future small scale producers. Similarly as waste management standards are revised, these should be thoroughly communicated as well.

ACTION IAEA: Consider / share waste technologies / technology developments emerging as outputs of this Working Group with current and future Mo-99 producers who may not be directly involved in the scope of this effort.

ACTION IAEA: Communicate changes in waste standards.

4. **RECOMMENDATIONS**

IAEA

- Develop a consolidated document with technical details of all proposed target designs
- Organize the participants of this CT into an International Working Group to support the conversion of large-scale, fission based Mo-99 production from HEU to LEU targets. The IAEA should organize annual meetings of the complete group and also work to progress activities on the margins of relevant international conferences such as the RERTR, IGORR, RRFM and TRTR as appropriate and in consideration of the planned attendance by relevant stakeholders. Representatives of other organizations (reactors who irradiate the targets, regulatory authorities, Tc-99m generator producers, government representatives, and target manufacturers) will be invited/encouraged to participate as deemed necessary at the time and in particular depending on the expressed needs of the major processing organizations.

ACTION USDOE/NNSA: Propose Terms of Reference for the International Working Group on Support for the Conversion of Major, Fission-based Mo-99 production from HEU to LEU.

- Relevant activities (meetings, publications, obtaining the services of experts and procurements

 if any) should be progressed as an international collaborative activity a collection of individual, albeit closely related, tasks. This approach permits work to proceed without delay (using extra-budgetary funding), protects existing intellectual property, and provides for the participation of all relevant stakeholders.
- Participate in all multilateral technology research and development work (target, front-end, back-end) as an observer; collecting, collating and disseminating information (and expressed needs) with respect to experience and future R&D.
- Review relevant regulatory requirements and consider a possible report to the Working Group (IAEA document or possibly a paper/presentation during a future Working Group meeting).

Technology developers

• Work toward technology demonstration first – to facilitate conversion. Then work with the major producers to optimize the selected designs (most likely via bilateral arrangements, non-disclosure agreements, etc.).

5. AGREED ACTIONS

5.1. ANL/G. Vandegrift

- Confirm if the scope of the baseline safety case will include licensing constraints within processing facilities.
- Define a detailed LEU-Foil target test plan and distribute to producers & KAERI in time for a detailed review during the RERTR (October 10-14).

- Gather information related to U₃Si₂ target development.
- Front-end processing work completed to date. G. Vandegrift to forward RERTR papers.

5.2. B&W/Y-12/L. Jollay

- Additional information on target supply costs to be provided November (report).
- Define a detailed LEU-Foil target test plan and distribute to producers & KAERI in time for a detailed review during the RERTR (October 10-14).

5.3. Covidien/L. Barbosa

- Work with target irradiation partners to finalize the list of bounding target qualification criteria and confirm / revise all bounding limits/acceptance criteria.
- Review U₃Si₂ information and recommend a path forward to the Working Group.
- Provide summary reports of all waste stream limits, regulations and any other relevant constraints.
- Inform IAEA of ownership of waste after transfer to COVRA.

5.4. GSG/H-J Roegler

• Obtain additional information from CERCA regarding the irradiation of 6 g/cm3 U_3Si_2 targets.

5.5. IAEA/E. Bradley

- Collect and distribute technology packages as discrete and complete sets of information in lieu of a piecemealed approach. Consider a website as an information store.
- Collect and distribute waste summary reports.
- Consider / share waste technologies / technology developments with current and future small scale Mo-99 producers.
- Communicate changes in waste standards.

5.6. INR/C. Toma

- Work with target irradiation partners to finalize the list of bounding target qualification criteria and confirm / revise all bounding limits/acceptance criteria.
- Define a detailed LEU-Foil target test plan and distribute to producers & KAERI in time for a detailed review during the RERTR (October 10-14). Review U₃Si₂ information and recommend a path forward to the Working Group.
- Review U3Si2 information and recommend a path forward to the Working Group.
- Provide summary reports of all waste stream limits, regulations and any other relevant constraints.

5.7. IRE/D. Moyaux

- Work with target irradiation partners to finalize the list of bounding target qualification criteria and confirm / revise all bounding limits/acceptance criteria.
- Review U₃Si₂ information and recommend a path forward to the Working Group.
- Provide summary reports of all waste stream limits, regulations and any other relevant constraints.

5.8. NIIAR/R. Kuznetsov

- Work with target irradiation partners to finalize the list of bounding target qualification criteria and confirm / revise all bounding limits/acceptance criteria.
- Review U₃Si₂ information and recommend a path forward to the Working Group.
- Discuss the potential for international for international collaboration to accelerate the current plans to convert Mo-99 production to LEU with NIIAR staff and communicate any opportunities back to the Working Group/IAEA.
- Provide summary reports of all waste stream limits, regulations and any other relevant constraints.

5.9. NTP/G. Ball

- Work with target irradiation partners to finalize the list of bounding target qualification criteria and confirm / revise all bounding limits/acceptance criteria.
- Review U₃Si₂ information and recommend a path forward to the Working Group.
- Provide summary reports of all waste stream limits, regulations and any other relevant constraints.

5.10. Sameh, A. A.

• Provide a list of publications detailing the work completed at Karlsruhe as well as the relevant patent or patents.

5.11. University of Missouri/C. Allen

- Confirm if the scope of the baseline safety case will include licensing constraints within processing facilities.
- Define a detailed LEU-Foil target test plan and distribute to producers & KAERI in time for a detailed review during the RERTR (October 10-14).

5.12. USDOE/NNSA/R. Hamilton

• Propose Terms of Reference for the International Working Group on Support for the Conversion of Major, Fission-based Mo-99 production from HEU to LEU.

6. SUMMARY OF PRESENTATION

6.1. P. Staples (USA – DOE/NNSA)

The current status and future plans of the Global Threat Reduction Initiative were presented. A status overview of the three principle goals within the GRTR Mission – convert, remove, and protect was provided. Seventy-two (of ~200 total HEU fuelled facilities) research reactors have been converted or verified to be shutdown, including all U.S. university research reactors that can convert with currently available fuel; 33 of these efforts have been completed since GTRI's 2004 inception.

Specifically, with respect to Mo-99 production, as part of its long-standing mission, in 2009 GTRI received the additional mandate to establish a reliable U.S. domestic supply of Mo-99, produced without the use of HEU. GTRI's approach includes assisting global Mo-99 production facilities to convert to LEU targets and accelerating the establishment of commercial, non-HEU-based Mo-99 production in the United States. GTRI provides non-proprietary technical expertise as well as proprietary-sensitive support to international HEU to LEU conversion efforts through multilateral and bilateral mechanisms. Many specific examples of support were cited in the presentation including international efforts facilitated by the IAEA and OECD/NEA.

Finally GTRI activities to demonstrate the viability of four non-HEU based technology pathways were summarized. The final 2 awards, based on LEU target technology and accelerator technology are targeted for award in September 2010.

6.2. A. Sameh (Independent expert, Germany)

Work to convert the Kernforschungszentrum Karlsruhe (KfK) production process developed in Karlsruhe, Germany was presented. This same process is currently operated by Covidien in the Netherlands under licence of KfK. Details of Covidien's current production gaseous releases, as determined by the International Monitoring Communities (IMC) were presented. The IMC was established by 16 countries including the USA. The related data were presented during the Workshop on Signatures of Medical and Industrial Isotope Production (WOSMIP) held in Strassoldo, Italy in 2009 and published by the US DOE in the report PNNL-19294 in February 2010. This information showed the daily and annual Xenon release to be 3 to 4 orders of magnitude below the other major producers.

Information (including many photos) was shared about the fabrication and irradiation of U₃Si₂ Mo-99 target plates. The required front end, the chemical processing and a uranium recycle process (demonstrated in Karlsruhe) were also presented.

The Karlsruhe process for the silicide dissolution is founded on the treatment of the silicide meat after the alkaline digestion of the cladding material in a potassium hydroxide solution. The meat is dissolved in a mixure of hydrofluoric acid and hydrogen peroxide and preferably iodide/iodate as a catalyst at ~ 20 C°. The reaction can be also catalysed by the related chloride and bromide compounds if the production of fission Iodine is desired.

Finally, some experience from CERCA on their U₃Si₂ plate development work was shared along with copies of a CERCA report on the subject.

6.3. G. Beyer (GSG, Germany/France)

The Rossendorf experiences in fission-based Mo-99 production were presented. A brief history was presented, including the development of three distinct production technologies: ROMOL-99, ROMOL-LITE and LITE-MOL – in order of decreasing scale. A history of Mo-99 / Tc-99m was also shared. A target design (natural U-metal) was discussed.

A detailed technical history of the Rossendorf Mo-99 technology development was presented, including the development of the AMOR-1 (1981), AMOR-2 (1986), and ROMOL-99 (2003). Included in the presentation are explanations of the organization's transition during the German reunification and the creation of the business that is today known as the Gamma Services Group (GSG). Information was shared regarding GSG's recent work in Pakistan where the ROMOL-99 process was installed.

Finally the concepts to support smaller-scale (distributed) Mo-99 supply were presented (ROMOL-LITE and LITE-MOL. ROMOL-LITE is a downscaled ROMOL-99 process based on Al-clad LEU UAl_x targets. LITE-MOL is a process based on ^{nat}U or very low enriched U metal as target material.

6.4. G. Vandegrift (ANL, USA)

Historical development work, design constraints and demonstration experience (in Indonesia, Argentina, Australia, and at the University of Missouri) were presented for the LEU, annular foil-target. By varying the fission-recoil barrier the target can be used in both acidic and alkaline based processes.

Because of the density of U-metal, metallic foil targets could easily achieve the desired ²³⁵U density to – when substituted for current targets – achieve equivalent or improved Mo-99 yields at end-of-bombardment (EOB).

Argonne is looking at two means to recover Mo-99 for use in alkaline processes: acidic dissolution followed by Mo recovery on ${\rm TiO_2}$ sorbent and electrochemical dissolution of U in carbonate media. In addition, Argonne's work related to the LEU-Modified Cintichem process was presented. A production scale dissolver is to be tested in October-January.

Finally, work related to the ultimate disposition of legacy waste from current HEU production was discussed. GTRI is currently assessing whether support can be provided to address the HEU in historic waste residue generated from the production of Mo-99.

6.5. C. Allen, (University of Missouri, USA) and L. Jollay (B&W/Y-12, USA)

The current status of the ongoing LEU-foil target development project was presented. The objectives of this project were described. The overarching goal is to manufacture a safe, but relatively inexpensive target to support the business case in favour of efforts to convert from HEU to LEU targets.

B&W/Y-12 will be responsible for manufacturing, testing and quality control, including the all required manufacturing, testing and inspection infrastructure. The University of Missouri will perform the necessary analyses, evaluations and independent verifications. The effort is being pursued in collaboration with INR/Pitesti where test coupon irradiation and post irradiation examinations will be conducted.

A number of details regarding target analysis and testing were shared to conclude the presentation.

6.6. G. Ball, (NTP, South Africa)

The background, strategic considerations and related project details associated with recent successful efforts of NTP to convert to an LEU based Mo-99 production process were presented. The prerequisites of NTP's initial (historical/1980s) Mo-99 project were defined and included high levels of expertise related to chemical processing, isotope separation, theoretical and experimental physics and a list of available site infrastructure facilities.

Strategic considerations undertaken by NTP during the SAFARI-1 fuel and Mo-99 conversion project planning phase included thorough techno-economic studies, a focus on the minimization of financial and operational risk and no changes to fuel or reactor core geometry. Furthermore, the conversion effort strove to minimize changes to the target, irradiation, handling and chemical process; aimed to retain production capacity and avoid any interruption in production.

The conversion project is being approached in two phases. The first relied on a U-Al dispersion target with minimum changes to the current processes in the reactor or processing facilities. The second will involve more significant changes to both but must first be shown to have significant benefits. The detailed stages of the first phase were presented. The product is currently undergoing the final stages of validation and the regulatory approval process is underway. Phase 2, not yet commenced, would begin with an investigation of an alternate target design and consider both higher yield as well as a reduction in waste volumes.

Detailed results of the Phase 1 effort were presented, showing no resultant safety or quality issues associated with the conversion (W-187 observed in some runs, but NTP Tc-99m generators fully comply with specifications).

Waste details were also shared. The activity of actinides and light elements in the LEU waste stream increase by factors of 3.4 and 5.4 respectively. Also NTP cited the waste storage challenge associated with the significant increase in uranium mass in the solid waste stream. The net effect is an increase in waste nuclide inventory per Ci of Mo-99. However, there were no criticality issues and liquid waste volumes remained unchanged.

6.7. B. Briyatmoko (BATAN, Indonesia)

Details of BATAN's efforts to convert from an HEU to LEU based fission Mo-99 production over the past 15 years were presented. Significant detail was shared regarding BATAN's target manufacturing capability. Other details related to the implementation of the LEU-Modified Cintichem process were also shared.

The conclusion, with respect to the significant efforts undertaken by BATAN in cooperation with ANL and the ongoing IAEA CRP:

- LEU foil target fabrication technology is ready for commercial production
- From the results of development of material production of Mo-99 from fission U-235 targets using low-enrichment uranium (LEU) can be concluded:
 - During four separate LEU foil target irradiation demonstrations, the resulting Mo-99 product met the requirements for radionuclide purity (Medy physical) permitting the technology to be used for the manufacture of raw materials for Mo-99/Tc-99m generators.

- \circ Radionuclide impurities γ transmitters and α transmitter meet the criteria established by Medy Physics
- Separation process and the cost of handling radioactive waste is cheaper because it does not use sulphuric acid in the separation process.

6.8. R. Cameron (OEDC/NEA)

The work of the OECD/NEA and efforts to clarify the costs of HEU to LEU conversion were presented. OECD/NEA efforts to assess the Mo-99 market were shared; including details of major failures in policy, technology and the market. The unsustainability of the upstream production process was discussed as well as the need to increase production prices. Conclusions from the NEA facilitated High Level Group on the Supply of Medical Radioisotopes (HLG-MR) also call for a revised pricing structure (providing for the full recovery of the costs of production) and adequate reserve capacity – funded from within the supply chain.

The NEA economic study outlined the limited and sometimes complete lack of data (costs and experience base) for LEU conversion and/or LEU based production, especially at large scale (1,000s of Ci per week). The presentation noted the lack of technology related information – in particular related to the commercial availability of high density uranium targets. A basic model was presented that highlighted the generally known and unknown costs of LEU conversion.

6.9. M. Stewart (ANSTO, Australia)

Details of SYNROC, a permanent waste disposition technology and ANSTO's specific plan to utilize this technology for Mo-99 solid and liquid waste streams were presented. The history of the technology development, description of the technology as well as the progression to a distinct business unit were presented. SYNROC's advantages, including its ability to accommodate a variety of waste forms, potential scalability, ability to permanently immobilize wastes and opportunities for significant volume reduction were detailed. Details of how ANSTO will disposition waste from the previous Mo-99 production process (1.8 to 2.2% enriched, acidic) as well as the current process (19.7% enriched, alkaline), using SYNROC and other waste management strategies were shared. This included an overview of the waste volumes. Examples of other SYNROC demonstrations in the USA and UK were also provided.

6.10. R. Kuznetsov (NIIAR, Russian Federation)

The status of efforts to establish Mo-99 production at the Research Institute of Atomic Reactors (NIIAR) in Dimitrovgrad was presented. The project is being implemented by ROSATOM via the consolidation of all available resources. The project was developed upon basic requirements for spare (back-up) capacity, reliable logistics, safety, environmental responsibility, and based on customer accepted technology. Multiple reactors will be capable of target irradiation (RBT-6, RBT-10/2, SM). The targets will be similar to others already in use. Two processing facilities are to be installed. This arrangement should ensure continuous production.

The strategic aims of the project are to rely in demonstrated and commercially available technology to quickly achieve production. A second processing line will be installed to achieve a higher production capacity. The first stage of the project will rely on an existing HEU target design and the processing equipment will be installed in existing hot cells. The second stage will rely on further developed target technology – but still HEU – with a new facility constructed to house new hot cells and the second processing line. The final stage of the project involves the development of an advanced (Zn) target design and the use of NIIAR's proprietary

dry processing technology (pyro-processing). The final stage brings the potential to convert to LEU as well as significantly increase production capacity.

The first stage should result in Mo-99 production before the end of 2010. Stage 2 is planned for 2012 and Stage 3 work is to commence in 2013.

6.11. C.-K. Kim (KAERI, Republic of Korea)

Current details of KAERI's foil fabrication technology were shared. The technique of foil production via cold roll casting was described. Foils as well as complete target assemblies have been distributed among participants of the IAEA CRP on Developing Techniques for Small Scale Indigenous Mo-99 Production Using LEU Fission or Neutron Activation. Positive results from irradiation of KAERI foils completed at MURR were shared including some evidence that foil oxidation may render a recoil barrier redundant.

Efforts to improve the rolling technology, to produce foils of more uniform thickness were presented.

The power point file also contained R&D work on U-Mo research reactor fuel, but was not specifically presented. This information, along with a technical paper on KAERI's U-foil was shared with all participants.

6.12. C. Toma (INR, Romania)

The technical feasibility of producing Mo-99 in a 14 MW TRIGA reactor and associated hot cells was presented. The basis for the project is to secure medical isotopes for the citizens of Romania, to improve the reactor's utilization and support global efforts to shift Mo-99 production away from HEU. The project is being pursued within the IAEA CRP on Developing Techniques for Small Scale Indigenous Mo-99 Production Using LEU Fission or Neutron Activation and is considering a U-foil target in combination with the LEU-Modified Cintichem process.

Details of the project plan and existing / available infrastructure (reactor, hot cells, transfer and handling systems, etc.) were presented together with site work to support the project (target manufacturing capability, irradiation rig, tooling, processing equipment, etc.). An irradiation device (12 targets) could produce approximately 800 6-day Ci., but current hot cell availability may limit actual production to less than this due to the inability to process the contents of one irradiation device simultaneously. To achieve large-scale production additional hot cells must be made available or constructed.

Additional information related to Mo-99 waste management as well as INR's Integrated Management System was included in the presentation file but not discussed during the CT. The file was distributed to all CT participants.

ANNEXES

ANNEX 1 - Tentative Agenda

Consultancy Meeting on Conversion Planning for Mo-99 Production Facilities from HEU to LEU

Vienna, Austria 24-27 August Room F0822

Tuesday, 24-August

08:00	Participants obtain badge – Gate 1 ¹
09:30	Meeting Opening N. Ramamoorthy (IAEA, Dir NAPC) P. Adelfang (IAEA, SH RRS & RR Cross-Cutting Coordinator) E. Bradley (IAEA, RRS)
	Introductions and selection of meeting Moderator
10:00	NNSA activities in support of the transition away from HEU in the Mo-99 production cycle. P. Staples (NNSA)
10:15	HEU and LEU Mo-99 production experiences including the use of high density and/or metallic uranium targets, Karlsruhe to Petten A. Sameh – independent expert
10:45	COFFEE
11:00	HEU and LEU Mo-99 production experiences including the use of high density and/or metallic uranium targets, Rossendorf to ITD (GSG). G. Beyer (Expert consultant to GSG)
11:30	HEU and LEU Mo-99 production experiences including the use of high density and/or metallic uranium targets, Argonne to MURR G. Vandegrift (ANL) C. Allen (University of Missouri) L. Jollay (B&W/Y-12)
12:00	LUNCH
13:30	Experiences of HEU to LEU Mo-99 production conversion: NTP G. Ball (NTP)
14:00	Experiences of HEU to LEU Mo-99 production conversion: BATAN B. Briyatmoko (PTBN-BATAN)
14:30	The LEU Mo-99 Business Case: OECD/HLG-MR report development – assumptions, unavailable data and related challenges R. Cameron (OECD)
14:45	COFFEE
15:00	SYNROC – Demonstrated capabilities, project status and related Mo-99 production applicability M. Stewart (ANSTO)

¹ Participants may also obtain their IAEA Grounds Pass on Monday 23-August. The Gate 1 Pass office is open until 15:00 hr. from June through August.

15:30 Group discussion: Identify barriers to conversion: faced by producers

Technical

Economic / Market Other (Political?)

17:30 Retire for the day

Wednesday, 25 August

09:00 Group discussion: Within the context of identified barriers to conversion, discuss, prioritise and identify necessary actions related to:

- 1. Ensuring continued deliveries of Mo-99 requirements
- 2. High-density (e.g. metal foil) LEU target design, testing/qualification, commercial availability
- 3. Irradiation rig and reactor issues (including safety issues, reactor cooling, etc.)
- 4. Process flow-sheet/dissolution chemistry, hot cell installations adaptation from existing situation
- 5. Safety and regulatory matters
- 6. Waste management
- 7. Cost and schedule estimates for LEU conversion milestones
- 8. Economic analysis of costs of LEU production
- 9. Need for "staging" of the conversion of existing reactors and processing facilities in order to minimize supply disruptions; and
- 10. Assistance to, or commercial relationships with, new LEU producers as technology demonstration platforms and for enhancing supply in advance of "brown-field" conversion

12:30 LUNCH

14:00 Group discussion: Work to organize identified actions into individual clusters of scope

Those with significant IP/proprietary challenges²

Those without significant IP/proprietary challenges (i.e. areas of potential IAEA support)

16:30 **Open meeting** – Argonne National Laboratory, B&W/Y-12, INR/Pitesti TRIGA, University of Missouri, US DOE/NNSA: High density target development project. All participants are welcome and encouraged to attend, or may otherwise retire for the day

19:00 **IAEA Hospitality**

Thursday, 26 August

09:00 Develop an activity breakdown structure for the identified scope clusters with potential for IAEA support (i.e. no significant proprietary challenges)

12:30 LUNCH

² The scope identified during this discussion will not be pursued further during this meeting.

Define organizations (present and not present) who could progress identified activities, develop a reasonable, preliminary timeline for individual activities

Discuss available mechanisms (within and external to the IAEA) to facilitate / progress the identified tasks by the relevant organizations according to the preliminary schedule

Retire for the day

Friday, 27 August

09:00 Review and consolidate previous discussion into a final meeting report

Presentation summaries

Barriers to conversion

Project(s) to overcome identified technical challenges – without significant IP concerns

Related work to develop LEU production based Mo-99 business case(s)

Summary of other issues to consider (safety, regulatory)

Summary of opportunities and available mechanisms to progress actions

Recommendations

12:30 LUNCH

14:00 Review and finalize report

16:00 Meeting closure

$ANNEX\ 2-List\ of\ participants$

Consultancy on Conversion Planning for Mo-99 Production Facilities from HEU to LEU

IAEA Headquarters in Vienna, Austria 24 to 27 August 2010, Meeting Room F0822

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