Phase-out of HEU Use for ^{99}Mo Production in Belgium and Netherlands

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Introduction

The recent shutdowns of the NRU reactor in Canada and the HFR in Petten, Netherlands and the subsequent ^{99}Mo shortages incurred by downtime at two of the world's primary ^{99}Mo production facilities have brought attention to the state of the global ^{99}Mo infrastructure. Efforts have been undertaken to secure the ^{99}Mo supply and stabilize the ^{99}Mo economy, and a number of producers have set sights on increasing their production in a market historically dominated by a small number of companies. In addition to this, increased attention has been drawn to the use of highly enriched uranium (HEU) in the ^{99}Mo supply chain. In light of the perceived dangers of civilian HEU use, a number of organizations, including the U.S. National Nuclear Security Administration (NNSA), the International Atomic Energy Agency (IAEA), the Organization for Economic Cooperation and Development Nuclear Energy Agency (OECD NEA), the National Academy of Sciences (NAS), and the Nuclear Threat Initiative (NTI), among others, have dedicated technical, economic, and academic resources to assess the role of HEU in the ^{99}Mo supply chain and work towards converting production to use low enriched uranium (LEU).

This paper provides new information about the technical capabilities of the producers and their efforts to convert to LEU-based production. It has been found, and will be subsequently discussed in greater detail, that Covidien and the National Institute for Radioelements (IRE) are receiving support from the NNSA and are working in the direction of conversion. Due to the processing capabilities at IRE, conversion could be undertaken without an interruption to supply. IRE estimates that full conversion could take 6-7 years if they were to use a foil or silicide target and work began immediately. However, according to IRE, conversion is not yet economically viable due to other technical and economic obstacles.

Field research has also shown that the majority of practical work being done to encourage conversion is a result of the NNSA's Global Threat Reduction Initiative (GTRI). Belgium and the Netherlands have declared their support for conversion as part of the Nuclear Security Summit (NSS), but neither government has provided tangible support to the production companies. Despite this, the issue has received increased attention from a number of Ministries within the Dutch government in recent months.

The efforts of the United States, Belgium, and Netherlands are particularly significant because, historically, the United States and Europe have accounted for the large majority of ^{99}Mo demand. This demand has been met by a small number of suppliers: As of 2009, Nordion of Canada, Covidien of Netherlands, and IRE of Beligum provide nearly 90% of the 12000 weekly 6-day

Ci demand,[1] though the relative production of the suppliers changes on a weekly basis. Regional suppliers, including Comisión Nacional de Energía Atómica (CNEA) of Argentina, NTP of South Africa, and the Australian Nuclear Science and Technology Organisation (ANSTO) of Australia, produce ^{99}Mo on a smaller scale and, until very recently, have not been involved in the global supply network. Nordion, Covidien, and IRE all produce ^{99}Mo by the same general process: irradiation of HEU targets, dissolution of the irradiated targets, and purification of ^{99}Mo from the dissolved target. The purified ^{99}Mo is then provided to ^{99m}Tc generator manufacturers. When the radiopharmaceutical is needed, a physician extracts ^{99m}Tc using the generator, then prepares the kit appropriate for the diagnostic exam being conducted.

The importance of the ^{99m}Tc-based radiopharmaceuticals makes a stable, reliable supply of ^{99}Mo extremely important. However, maintaining this supply is particularly difficult due to the inability to stockpile ^{99}Mo as a result of its short half-life. This, along with the proprietary nature of some production processes, introduces special considerations for the nonproliferation community's efforts regarding isotope production. Nonproliferation efforts focused on other nuclear facilities, such as research reactors and critical assemblies, often encourage consolidation or decommissioning of the facilities, as discussed by other reports

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[1] OECD, "The Supply of Medical Radioisotopes: Interim Report of the OECD/NEA High-level Working Group on Security of Supply of Medical Radioisotopes," 2010.

in this project. The isotope production infrastructure cannot be similarly downsized, so the primary goal of the nonproliferation community is to determine the feasibility of meeting the ^{99}Mo supply without the use of highly enriched uranium.

Pressure has been applied by the nonproliferation community to the large-scale producers to work towards conversion of their production techniques. Conversion efforts by Nordion, as well as past conversion by NTP and the CNEA are discussed in separate studies for this project. This research sets out to assess the feasibility of conversion by Covidien in Netherlands and IRE in Belgium, as well as to determine the state of conversion efforts by both companies.

A review of the literature regarding ^{99}Mo production and conversion is provided in the next section, followed by a description of the methodology used to conduct the present research including interviews with European officials. Following a full summary of the results, the paper concludes with recommendations to encourage conversion based on the findings.

Literature Review

Early investigations showed that processing techniques similar to HEU target processing could produce ^{99}Mo from LEU targets[2] at minimal penalty to ^{99}Mo purity or yield per unit ^{235}U.[3] Some issues with ^{99}Mo production with LEU targets were identified as well, however these issues, such as increased waste volume[4] and increased ^{239}Pu production[5] are not seen as prohibitive. Higher density fuels, such as uranium silicides (U_3Si_2) and uranium foils have been produced and tested.[6] Dispersion targets have been proven as viable targets and are already in use commercially with chemical processing techniques identical to those used for HEU targets.[7] LEU targets are also used by commercial ^{99}Mo

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[2] A.A. Sameh and H.J. Ache, "Production Techniques of Fission ^{99}Mo" (paper, Fission Molybdenum for Medical Use, Karlsruhe, Germany, October 13-16, 1987).

[3] George F. Vandegrift et al, "Preliminary Investigations for Technology Assessment of ^{99}Mo Production From LEU Targets" (paper, Fission Molybdenum for Medical Use, Karlsruhe, Germany, October 13-16, 1987).

[4] Vandegrift, Preliminary Investigations 110.

[5] Frank Von Hippel, "Feasibility of Eliminating the Use of Highly Enriched Uranium in the Production of Medical Radioisotopes," *Science and Global Security* 14.2-3 (2006): 151-162.

[6] C. Conner et al, "Progress in Developing Processes for Converting ^{99}Mo Production from High- to Low-Enriched Uranium," (paper, 1998 International Meeting on Reduced Enrichment for Research and Test Reactors, Sao Paolo, Brazil, October 18, 1998).

[7] Steven van der Marck, "The options for the future production of the medical isotope 99Mo," *European Journal of Nuclear Medicine and Molecular Imaging* 37.10 (2010): 1820.

producers in South Africa and Australia.[8] Other ^{99}Mo production techniques, such as activation of ^{98}Mo, accelerator production, and liquid core reactor production have been investigated as a means of alleviating some of the recent supply shortages due to temporary shutdowns of NRU in Canada and HFR in Netherlands but none are yet able to come close to meeting the current demand.[9]

Estimates of the costs associated with conversion to LEU targets suggest that conversion is viable with a minor increase in the price per dose of the radiopharmaceutical. One cost estimate for the conversion of Covidien's facilities at Petten is $10 million, a cost that could be offset by an increase in the price of the radiopharmaceutical of less than 1%.[10] It should be noted, however, that the industry has stated that the National Academy of Sciences underestimated these conversion costs, as well as the regulatory hurdles incurred by conversion.[11] Additional estimates of the costs along the supply chain were made by the OECD High-level Working Group on Security of Supply of Medical Radioisotopes

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[8] Alan J. Kuperman, "The Global Threat Reduction Initiative and Conversion of Isotope Production to LEU Targets," (paper, 2004 International Meeting on Reduced Enrichment for Research and Test Reactors, Vienna, Austria, November 7, 2004).

[9] Dewi M. Lewis, "(^{99})Mo supply--the times they are a-changing," *European Journal of Nuclear Medicine and Molecular Imaging* 36.9 (2009): 1371-4.

[10] Von Hippel, 156.

[11] Roy W. Brown, "Global Mo ^{99}/Tc ^{99}m Supply: Current State and Future Opportunities," (presentation, Covidien User Meeting, June 15, 2009).

(HLG-MR) in its interim report.[12] Based on these estimates, it was concluded that even substantial increases in reactor costs to the producers would not result in substantial increases in the patient cost of the radiopharmaceutical, although this report did not explicitly address the effects of conversion on costs along the supply chain.[13]

In terms of current production, target irradiation takes place at a number of facilities, including HFR in Netherlands and BR-2 in Belgium. Covidien and IRE utilize both reactors, among others, then process the targets at their respective facilities in Petten, Netherlands and Fleurus, Belgium. Both companies use annular or plate targets[14] with U-Al alloy constituting the target meat,[15] and process the targets by alkaline dissolution.

NRG, the operator of HFR, has announced plans to construct the Pallas reactor, a new facility with ^{99}Mo production capabilities. In light of the advertised construction date of 2016, Covidien has said it will first develop LEU production techniques for Pallas then investigate the use of those techniques for

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[12] OECD, 2010.

[13] Harrie Seeverens, "The economics of the Molybdenum-99/Technetium-99m supply chain," *Dutch Journal of Nuclear Medicine* 32.4 (2010): 606.

[14] National Academy of Sciences, *Medical Isotope Production Without Highly Enriched Uranium* (Washington D.C.: National Academies Press, 2009) p. 24.

[15] See note 6 above.

the conversion of targets at HFR if it is still operating.[16] Covidien has not provided specifics on its LEU conversion research. IRE has previously stated that it is not pursuing conversion, nor has it discussed any research regarding LEU technologies, though the National Academy of Sciences believes conversion at Petten by Covidien would likely force IRE to convert.[17]

Initial U.S. legislation regarding ^{99}Mo production, in the form of the Schumer Amendment to the 1992 Energy Policy Act, required that producers agree to conversion to an alternative target, once viable, in order to receive HEU exports from the United States in the interim prior to conversion.[18] These restrictions were lifted by the Burr Amendment to the 2005 Energy Policy Act, which exempted Canada and Europe from the provisions of the Schumer Amendment regarding HEU exports for isotope production.[19] More recently, the proposed American Medical Isotope Production Act allocates funds for development of a domestic, LEU-based ^{99}Mo production infrastructure[20] and includes a provision to prohibit HEU exports within 7-13 years after the

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[16] National Academy of Sciences, 120.

[17] National Academy of Sciences, 122.

[18] Alan J. Kuperman, “Bomb-grade bazaar,” *Bulletin of the Atomic Scientists* 62.2 (2006): 44-50.

[19] National Academy of Sciences, 12.

[20] United States, House of Representatives Subcommittee on Energy and Environment. “American Medical Isotopes Production Act of 2009, Section by Section Summary,” http://energycommerce.house.gov/Press_111/20090908/hr3276_%20sectionbysection.pdf

legislation is passed, depending on the state of U.S. supply a that point.[21] The bill is currently in committee in the Senate, however similar bills stalled in the Senate in previous Congressional sessions, though one of the primary opponents to previous versions is no longer in the Senate.[22] Conversion of isotope production was also a focus of the 2010 Nuclear Security Summit. A provision of the work plan for the Summit states:

> Participating States, as appropriate, will 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.

This plan was agreed upon by all states participating in the NSS, including Belgium, Canada, and the Netherlands.[23]

The body of literature regarding ^{99}Mo production is substantial. In addition to the large-scale assessments of the global ^{99}Mo scene by the National Academies and the OECD NEA HLG-MR, there exists an array of articles regarding the state of LEU target research, meeting proceedings from the various

[21] "Text of S.99: American Medical Isotopes Production Act of 2011," Civic Impulse, http://www.govtrack.us/congress/billtext.xpd?bill=s112-99

[22] "Sen. Bond blocks debate on American Medical Isotope Production Act," *Columbia Missourian*, July 22, 2010, http://www.columbiamissourian.com/stories/ 2010/07/22/bond-blocks-bill-expand-nuclear-medicine-tests/

[23] "Nuclear Security Summit at a Glance," Arms Control Association, http://www.armscontrol.org/factsheets/NuclearSecuritySummit

IAEA working groups, and publications from the producers. As a result, much of the ^{99}Mo production scene is well documented and well understood. That said, one major obstacle in accurately assessing the feasibility of conversion is the proprietary nature of ^{99}Mo production processes. This often renders claims about production capabilities and the difficulty of conversion as somewhat speculative.

It should also be noted that the ^{99}Mo production scene is highly dynamic and publications can be rendered out-of-date rather quickly. The technical capabilities of the production companies and their public position on conversion, the number of producing countries and companies, the state of U.S. policy, and the state of LEU target research have all changed even in the last few years.

In light of the substantial nature of the relevant literature, many of the crucial questions regarding conversion have, at least, been asked, if not already partially answered. Many of the important questions were not new, however they did warrant revisiting in order to provide the most up to date information. This study provides updated information on a number of the existing questions and provides new insight by addressing questions that have not been answered elsewhere in the literature.

Methodology

Field research was conducted in order to answer the following questions relevant to isotope production in Belgium and the Netherlands:

- What is the current state of conversion plans and research by IRE and Covidien, if any? If either company is pursuing conversion, which type of target would be utilized? Would processing and irradiation occur at the same facilities as current production?

- From the perspective of the producer, are there prohibitive technical or economic obstacles?

- How many processing lines do Covidien and IRE utilize? If either company uses only one, would they construct additional lines during conversion? If either company uses two lines, would conversion occur incrementally? Would either company maintain both HEU and LEU processing lines for targets from different facilities?

- Who are the HEU suppliers for Covidien and IRE? Is the reliability or availability of future supply a concern?

- How much HEU per year do Covidien and IRE consume? How much HEU does each company have stockpiled for target production? What is done with the spent material?

- If Covidien begins production at Pallas using LEU targets, would it convert to LEU targets elsewhere or would it use both HEU and LEU targets? Does it plan to build a new process line for LEU targets or convert an existing line?

- Are there regulatory hurdles that are prohibitive even if conversion becomes economically viable? If so, what reform could be enacted to overcome this hurdles?

- What efforts has the US made to encourage conversion?

- Are Covidien and/or IRE concerned about a potential U.S. tariff on, or prohibition of, the import of isotopes produced with HEU? Does either possibility affect plans to convert?

There are a number of entities relevant to ^{99}Mo production outside of the producers themselves that were potentially useful in answering these questions. Policymakers in the government, research organizations, regulatory agencies, reactor operators, ^{99m}Tc generator manufacturers, and others are responsible for some element of the ^{99}Mo production infrastructure. Contacts at many such relevant organizations in Belgium and Netherlands were pursued for the purposes of this research. Additionally, questions were directed to the NNSA due to their role in current conversion efforts.

Personal interviews were conducted with Dominique Moyaux of IRE in Belgium and Dr. Harrie Seeverens of the Ministry of Health, Welfare, and Sport in Netherlands. Questions were directed to Dr. Parrish Staples and Rilla Hamilton of the NNSA when they visited the research group at the University of Texas, and a follow up phone interview was conducted with Ms. Hamilton. Email exchanges were also conducted with Dr. A.A. Sameh, the scientist who originally developed the ^{99}Mo recovery process, Fred Wijtsma of NRG, Luis Barbosa of Covidien, and Frank von Hippel of Princeton University.

The proprietary nature of operations and business strategy of the producers posed an obstacle to the research. As a result, representatives at both companies were either unable or unwilling to answer certain questions related to the project. Representatives at the NNSA were similarly unable to answer some questions in consideration of their collaborative efforts with the ^{99}Mo producers, and other organizations deferred questions to the producers.

In the case of Covidien, no representative was reached who was willing to answer any of the research questions specifically. Thus, many of the technical findings given in this paper are a result of the cooperation of IRE. Responses to the same questions by Covidien would provide a more comprehensive and fruitful assessment of the prospects and challenges of conversion.

Findings

Conversion Efforts

IRE is currently collaborating with the NNSA on conversion research and has taken part in the IAEA Conversion Planning working group. As part of the working group, IRE and Covidien have agreed to finalize the bounding criteria for foil targets, recommend research to further develop U_3Si_2 targets, and provide information on the waste management regulation they face in production. Based on discussion of IRE's processing capabilities below, it does not seem that new facilities would be required for conversion. IRE estimates that it could 6-7 years, if it began today, to establish a complete LEU-based ^{99}Mo production infrastructure if conversion were undertaken with a uranium foil targets or silicide targets.[24] This timeframe would be shorter if conversion utilized UAl_2 dispersion targets.

Technical and Economic Obstacles

According to Dr. Moyaux, the Belgian government has pushed to reduce the gas emissions associated with ^{99}Mo production. In light of the higher levels of effluents with acidic dissolution, front end processing of LEU targets would have to continue using some form of alkaline dissolution process. Additionally, changes to the bulk material of the target,[25] necessitated by conversion to foil or U_3Si_2 targets, would require more substantial changes to the processing techniques and would pose new waste management concerns as the waste composition or volume would be sufficiently different. Further, processing of U_3Si_2 LEU targets with the current Sameh-developed techniques could damage IRE hot cells, and additional modification may be necessary to support such processing. Accounting for these considerations, the LEU foil target, an annular target with an LEU foil pressed between cylindrical aluminum cladding, appears to be the preferred and most likely conversion route.

[24] Domininque Moyaux (Production Manager, IRE), in discussion with the author, March 2011

[25] Such as conversion from a U-Al alloy to a U_3Si_2 target.

Dr. Moyaux noted additional concerns regarding conversion to foil targets beyond the changes that would have to be made to the dissolution and purification processes. At present, the foil targets have not been qualified for large-scale reactor irradiation. Further, a supplier of raw material for LEU foils and a producer of foil targets for large-scale production has not yet been established.

Although use of UAl_2 dispersion targets (the current technology utilized by NTP in South Africa and CNEA in Argentina) would require minimal changes to the dissolution process at IRE and could alleviate target material supply issues, the number of LEU targets irradiated would have to increase in order to maintain output as the target density for UAl_2 is not yet high enough to produce the same ^{99}Mo yield per target as HEU. Increasing the number of targets could require more irradiation positions in reactor facilities and new container designs, as current transportation is limited to 3 irradiated targets per container.

The NNSA has stated that development of foil targets has been completed and that work on qualification and front end processing of the targets has begun at Argonne.[26] According to Argonne and IRE, the foil targets have been developed sufficiently such that the per-target yield is equivalent to that of

[26] Rilla Hamilton (Policy Analyst, NNSA), in discussion with the author, February 2011.

the current HEU targets.[27] These targets would initially cost more for the producers but the change in the cost over time is unknown.[28]

Beyond specific technical obstacles described by IRE, there are also substantial economic issues plaguing the ^{99}Mo market, inhibiting a precise assessment of the economic impact of conversion. The governments in some producing countries have only recently become aware of the extent to which government funding affects the molybdenum market.[29] By paying for operations and maintenance of the research reactors at which targets are being irradiated, the governments in Belgium and Netherlands, among other countries, are effectively subsidizing ^{99}Mo production and artificially reducing the reactor costs to Covidien and IRE. These subsidies are the reason that the ^{99}Mo market is currently deemed unhealthy and unsustainable.[30] Upon publication of the final HLG-MR report, these subsidies will be scaled back and reactor costs increased according to recommendations in the report. The market value of the reactor operations could be 5-7 times higher than current costs, according to Seeverens.

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[27] George Vandegrift, "HEU vs. LEU Targets for ^{99}Mo Production – Facts and Myths" (presentation, Oslo Symposium on the Minimization of Highly Enriched Uranium in the Civilian Sector, Oslo, Norway, June 18, 2006).

[28] Hamilton, Feb. 2011.

[29] Harrie Seeverens (Policy Advisor, Netherlands Ministry of Health, Welfare, and Sport), in discussion with the author, March 2011.

[30] Hamilton, Feb. 2011.

Cooperation between producers may be necessary to evaluate and properly manage the post-subsidy market but the extent of this cooperation would be limited by concerns of anti-trust restrictions.

The economic and technical obstacles appear to be the most substantial to overcome to convert ^{99}Mo production. Although licensing of targets, once approved by the producers, may take some months, it is not seen as the prohibitive step in the conversion process.

Supply Interruptions

According to Moyaux, conversion at IRE would not cause an interruption in production. IRE maintains two processing lines, one consisting of a series of 6 hot cells and the other a series of 3 cells. Different steps of the dissolution and purification process are conducted in each cell. Last year, production took place exclusively on the first line until refurbishment of the second line was completed in September of 2010. Conversion to a new target material would require modification to processes in the first three cells of the production line, however this could be done without interruption by shifting work in cells 1-3 to the second line. The processing cycle would then utilize cells 1-3 of line 2, and cells 4-6 of line 1. Decontamination and modification of line 1's first three cells would take approximately 18 months, at which point the LEU-based processing would move back to line 1.

Similar conversion would not be possible at Covidien, which utilizes both of its processing lines simultaneously. Conversion would likely require construction of a new processing line, or a temporary interruption to operations, although this was not confirmed by Covidien.

HEU Supply

IRE's HEU comes from a European committed stockpile exported from the United States. IRE did not comment on concerns about the reliability of future HEU supply, nor could IRE provide numbers regarding their HEU stockpile or consumption rate. According to Moyaux, spent target material is reprocessed after 2-3 years for the purposes of strontium extraction, but not for ^{99}Mo production. IRE could not provide further waste disposal details.

The Role of Pallas in Conversion Planning

It seems widely agreed that the beginning of production at Pallas marks a deadline for conversion,[31] as LEU processing techniques will have to be developed for production at the new facility, which will be licensed only for LEU-based production. It is not known if IRE will use the reactor facilities at Pallas for irradiation. It should be noted that the initial projections of Pallas beginning

[31] Seeverens, March 2011 and Fred Wijtsma (Reactor Manager, NRG), email message to author, February 2011

operations in 2016, as mentioned in the literature review of this paper, were overly optimistic as the facility is now expected to be completed no sooner than 2018 - 2020.[32] This delay is the result of funding issues.

Government Involvement

The NNSA has worked with international producers to research LEU based technology and has provided financial support for conversion but it cannot comment on specific collaborations with companies.

When asked about support from the United States, Moyaux stated that IRE is receiving all the assistance it requires in terms of conversion research but the extent to which the NNSA can work with IRE is limited. Any research and techniques funded by the GTRI cannot be patented by the IRE, so any modification or overhaul of the back-end processing would have to be developed solely by IRE.[33] The producers have requested that the NNSA provide a conversion package proving the viability of all LEU-based processing steps with the exception of purification in order to facilitate their conversion.[34]

According to Seeverens, the Netherlands government, despite its support for conversion, has taken no practical steps to motivate conversion by Covidien.

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[32] Seeverens, March 2011.

[33] Moyaux, March 2011.

[34] "Conversion Planning for Mo-99 Production Facilities from HEU to LEU," (working materials, IAEA working group, Vienna, Austria, August 24-27, 2010).

Discussion of conversion has increased among a number Ministries within the government of Netherlands, however it remains to be seen if this will translate into action. The Ministry of Foreign Affairs supports the agreements laid out in the Nuclear Security Summit work plan but there is disagreement within the government on how to put the agreement into action. Likewise, the Belgian government does not appear to have taken any concrete steps to encourage or discourage conversion.

Summary of Findings

Field research for this project has found a number of answers to the questions previously posed. Though the companies are not specific about the state of their conversion research, it appears that both Covidien and IRE are preparing for eventual conversion. For IRE, conversion should be possible without an interruption to production. Based on interviews at IRE and the state of research at Argonne, LEU foil technology seems to be the preferred replacement for its HEU targets.

The outlook for the ^{99}Mo economy is ill-defined in light of recent supply shortages and the newfound awareness of instability in the ^{99}Mo market. This makes it difficult to foresee how the economics will change if conversion is undertaken, a fact that leaves producers claiming conversion is not yet economically viable.

The construction of the new Pallas reactor and production facility seems to stand as a conversion deadline for Covidien and IRE. However this timeline for construction has been pushed back to 2018 - 2020 and it is not known if the companies will pursue conversion prior to Pallas.

The NNSA has ongoing projects with the major producers to support their conversion research, and various working groups have been established to sustain collaboration between producers and outside organizations. U.S. policy has motivated conversion to an extent but the establishment of a domestic, LEU-based production infrastructure does not appear to be a substantial impetus for conversion elsewhere. This may be a result of earlier dynamics, such as supply issues or the construction of Pallas, driving the schedule.

Conclusions

Statements by Covidien[35] and the ongoing efforts of IRE indicate that the producers recognize the inevitable shift away from HEU-based ^{99}Mo production. It seems that both Covidien and IRE are currently working towards conversion, based on their collaborative efforts with the NNSA and participation in the OECD and IAEA working groups, though the extent to which research and development is being conducted on their proprietary processes is still unknown.

It is also clear that the construction of facilities at Pallas is a deadline for conversion. Covidien is likely to convert in order to move production to Pallas. The probable shutdown of HFR after Pallas goes online would likely force IRE to convert, if it has not already at that point, in order to continue using irradiation facilities in Netherlands. With the initial estimate of operations beginning at Pallas in 2016, it appeared unlikely that conversion would occur prior to the start of production at that facility. However, the recently announced delay of Pallas to the 2018 - 2020 timeframe puts pre-Pallas conversion back on the table. If the American Medical Isotope Production Act of 2011 is passed, the start of the 7-13 year window for ceasing HEU exports would coincide closely with the construction of Pallas, bolstering this deadline. The remaining questions, then,

[35] "FDA clears Covidien's low-enriched uranium based isotope production," Health Imaging, last modified March 11, 2011, http://www.healthimaging.com/index.php?option=com_articles&article=26715

are whether conversion will precede the opening of the new facility in Petten, and by which route the major producers will choose to convert.

Although the agreements at the Nuclear Security Summit are an encouraging sign that the governments of Belgium and Netherlands would like to support conversion, neither has taken concrete action similar to that of the United States, such as developing policy restricting HEU use.

The ^{99}Mo economy is in a state of flux with new producers working to become large-scale suppliers, new facilities, like the MARIA reactor in Poland, being utilized for target irradiation, and the entire global infrastructure working towards stabilizing the reliability of supply and making the ^{99}Mo market sustainable. In the absence of a mandate for conversion, the priority of the global producers to likely to remain fixed on stabilizing the ^{99}Mo economy rather than accelerating their conversion efforts.

Recommendations

It will be vital for the future of conversion efforts to enact a version of the American Medical Isotope Production Act that includes a prohibition of HEU exports for medical isotope production. With Nordion recently entering an agreement with Russia that will see Russian ^{99}Mo supplied to Nordion, it would also be beneficial to work with Russia in ending their use of HEU for ^{99}Mo production such that major producers could not simply rely on Russia after the United States ends its exports.

It might also be fruitful to apply some pressure to the signatories of the Nuclear Security Summit agreement to start crafting policy to motivate conversion by their producers, such as a tax on HEU-based ^{99}Mo production or tariff on the import of HEU-based ^{99}Mo. According to Dr. Seeverens, conversion will happen once proper policy is in place, and waiting 10 years for the construction of Pallas to convert is not reasonable.

Research on the technical feasibility of conversion and the development of LEU-based targets and processing techniques has been ongoing for decades and will assuredly continue to be instrumental in the shift away from HEU-based ^{99}Mo production. Due to the recent supply shortage, an increasing amount of research is being conducted on the ^{99}Mo economy as well, but only a small portion of this research is focused on conversion. More work should be conducted to assess the economic impact of conversion specifically, especially considering other changes likely to occur in the supply chain in the near future and to address producer concerns about cost increases resulting from conversion. If such research is undertaken, it would be crucial to include the major producers so as to minimize the speculative nature of cost estimates and economic predictions.

Collaboration between external organizations, such as the OECD, IAEA, and U.S. government, has also been an important part of the conversion effort, but with the release of the final HLG-MR report in the summer of 2011, the HLG-MR will be phased out.[36] Collaboration between these groups should continue with an increased focus on the economic effects of conversion. Follow up meetings to the August 2010 IAEA-organized Conversion Planning meeting could maintain this collaboration, as could a follow up group to the HLG-MR. This HLG-MR follow up is probably, according to Seeverens. Additionally, information from Covidien regarding their technical capabilities and conversion plans, similar to information provided by IRE, would provide a clearer picture of how the producers can be best supported in their efforts to convert.

In the long-term, continued reliance on $^{99m}Tc/^{99}Mo$ may require development of other production technologies altogether. Continued research on these alternative techniques, and the diversification of the global ^{99}Mo supply regime to include these technologies once mature, will ensure a reliable supply of ^{99}Mo in the future.

[36] Seeverens, March 2011.

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