# Assessing the Market Effects of Conversion to LEU targets for $^{99}$Mo Production

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## ABSTRACT

The conversion to using LEU targets for the production of $^{99}$Mo has been agreed to by all major $^{99}$Mo-producing nations. The NEA is studying the economic and supply impacts of conversion and the conversion process. This study will fill a gap in current analysis, which has generally been technical or have focused on the economics of a single facility. The overall goal of the study is to use a micro-economic assessment of the impact on an individual facility within the supply chain to develop a macro-economic assessment of the impacts on the whole market supply chain. Economic and capacity models of the supply chain are being developed and an analysis undertaken of various conversion scenarios and their impact on the global and regional $^{99}$Mo supply chain structures, in comparison to a reference case. This paper will describe the study being undertaken by the NEA, preliminary results and next steps.

## 1. Introduction

The conversion to using Low-Enriched Uranium (LEU) targets for the production of molybdenum-99 ($^{99}$Mo) has been agreed to by all major $^{99}$Mo-producing nations, most recently through the work plan of the Washington Nuclear Security Summit. In addition, the OECD Nuclear Energy Agency (NEA), in the policy approach of its High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR), has recommended actions that support the conversion to LEU targets.

However, this conversion will have many potential impacts on the global and regional supply chains of $^{99}$Mo and technetium-99m ($^{99m}$Tc). These impacts – known, perceived or uncertain – on both the production capacity and the costs of production are often cited as barriers to the conversion process; in some cases the impacts are cited as reasons for delaying the conversion process, with supply chain participants requiring additional study before they proceed to significant investment.

Recognising that conversion will occur, it is important to develop a credible and reasonable expectation of the impacts and, if necessary, develop recommendations for actions to address those impacts that could have a serious affect on security of supply of these important medical isotopes. As a result, the NEA is undertaking a study of the economic and supply impacts of conversion to using LEU targets and the conversion process. Given that the conversion is being undertaken for important non-proliferation reason, governments are imposing an externality on the market, which will be addressed by the policy recommendations where required.

This NEA study, being undertaken with supply chain stakeholders, seeks to fill a gap in past or on-going analysis on LEU conversion for $^{99}$Mo production. Most analysis has been generally technical in nature. Those studies that have examined the economic impacts have tended to focus on facility-level impacts and have not expanded the study to look at the impacts on the whole supply chain.

From the research already undertaken by the NEA, the main issues related to LEU conversion are the costs, the feasibility and the timescales of conversion. The first two issues are directly related to the uncertainty around final target design (especially the achievable density of the uranium in the target), the impacts on product yield of that design and the requirements for new builds versus conversion of existing processing facilities and if applicable, reactors. Although target design is predominately a technical issue, the impacts on a number of economic and supply variables stemming from the timing and the technical uncertainty is one issue the NEA is seeking to explore – identifying the most important economic and supply impacts and, where possible, offering policy options.

**2. The Project**

To increase understanding of the economic and supply chain impacts of converting to using LEU targets for the production of $^{99}$Mo, the NEA will use a micro-economic assessment of the impact on individual facilities within the supply chain to develop a macro-economic assessment of the impacts on the whole market supply chain. A capacity model and an economic model of the supply chain will be developed and analysis undertaken of various conversion scenarios and their impact on the global and regional $^{99}$Mo supply availability and costs, in comparison to a reference case. From there, an analysis of the costs of conversion would be undertaken, including costs that would be expected as a result of dealing with any supply shortfalls. In the first stages of the project, this assessment would assume the maintenance of current targetry and practices.

For the next stage of the project, the assumption on current targetry and practices would be varied. The scenario development and cost analysis would be repeated, allowing for changes to targetry and related practices, such as increasing density beyond currently commercial or near-commercial available targets or, if known and feasible, using alternative target types (e.g., foil targets).

Using the findings from these stages, the NEA and its HLG-MR will develop policy options and recommendations related to the economic and supply chain impacts of conversion. The recommendations will seek to encourage a smooth market transition to using LEU targets. For example, financing options during the conversion process could possibly be identified and analysed.

This project will be undertaken through a mixture of workshops, research and reporting, and economic modelling. The outputs will be aimed at informing policy makers and supply chain participants, helping them fulfil their conversion goals. The final report would provide a comprehensive overview of the findings from the full project and policy options and recommendations to accelerate and harmonise LEU conversion efforts. Below is a summary of the proposed full project.

Part A: Assessment of economic/supply impacts of conversion with current targetry and processes

1. Development of model of $^{99}$Mo supply chain
   The NEA will develop models of the current global $^{99}$Mo supply chain that would provide the capacities, distributions of product and costs of the current supply chain. These models will draw from the work of the NEA's economic study (*The Supply of Medical Radioisotopes: An Economic Study of the Molybdenum-99 Supply Chain)*, especially regarding costs and end-user impacts. The two models (one on cost, one on capacity) will

serve as reference cases to be used for comparison purposes to determine the impact of conversion on costs and capacity.

2. Identification of possible global supply chain impacts
   The NEA has already hosted a workshop with market participants to identify the perceived impacts of conversion at the facility level and on the global supply chain, in regards to costs and capacity and the related infrastructure needs for production, waste and outage reserve capacity (see below for more information on the workshop and follow up action).
3. Modelled supply chain and assessed impacts of conversion
   Using the model developed under task 1 and the impacts identified in task 2, the NEA will evaluate various scenarios related to timing of LEU conversion and the impacts on the entire global market and on regional markets, including related to supply vs. demand and economic variables.
4. Workshop: Model validation and shortage-coping methods
   A workshop will validate the model and its findings. Consensus on the best timing scenario will be sought. The workshop will also discuss methods that could be used to address any expected supply shortfalls if the model determined that shortfalls would occur, based on maintaining the same targetry and processes (e.g. staff increases, building infrastructure, using alternative production technologies).
5. Impacts of conversion with current targetry and processes modelling
   The global supply chain model and the economic model will be used to determine the impact of the various methods (from task 4) and the costs of dealing with the shortfalls. The cost of conversion on the global supply chain and, as reasonably as possible, at a facility level will be obtained. The expected impact on the price of $^{99}$Mo and $^{99m}$Tc through the supply chain will also be determined.
6. Produce a report on results
   A report would be written that would provide the results from Part A.

Part B: Assessment of economic/supply impacts of conversion with adjusted targetry and processes

7. Modelled supply chain and assessed impacts of conversion
   Working closely with the IAEA, the NEA will develop and assess various conversion scenarios based on technology-side options (changing targetry and/or processes). These scenarios will then be incorporated into the model to determine the impacts on regional and global supply chains, including related to supply vs. demand and economic variables. Price impacts on the supply chain, including on end users would also be determined following the economic model used for the economic study.
8. Impacts of conversion with technology options modelling
   The model will be used to apply shortage-coping methods suggested under task 4, layered on top of the technology-side option scenarios, to determine the impact of the various methods and the costs of dealing with the shortfalls. The cost of conversion on the global supply chain and, as reasonably as possible, at a facility level will be obtained. The expected impact on the price of $^{99}$Mo and $^{99m}$Tc through the supply chain will also be determined.
9. Workshop: Technology-side option validation and scenario selection
   A workshop will be held to validate the modelling and the findings from Part B and to reach consensus on a few best conversion scenarios. A report would be developed on the findings from Part B.

Part C: Policy Options and Recommendations

10. Develop policy options and recommendations
    The NEA and its HLG-MR will work with supply chain stakeholders to develop policy options to encourage the realisation of the best conversion scenarios and that would address the specific issues that may be faced by those scenarios, with a goal of accelerating and smoothing the market transition to using LEU targets. A workshop will validate the various policy options and recommend an approach to achieve LEU conversion.
11. Produce a final report

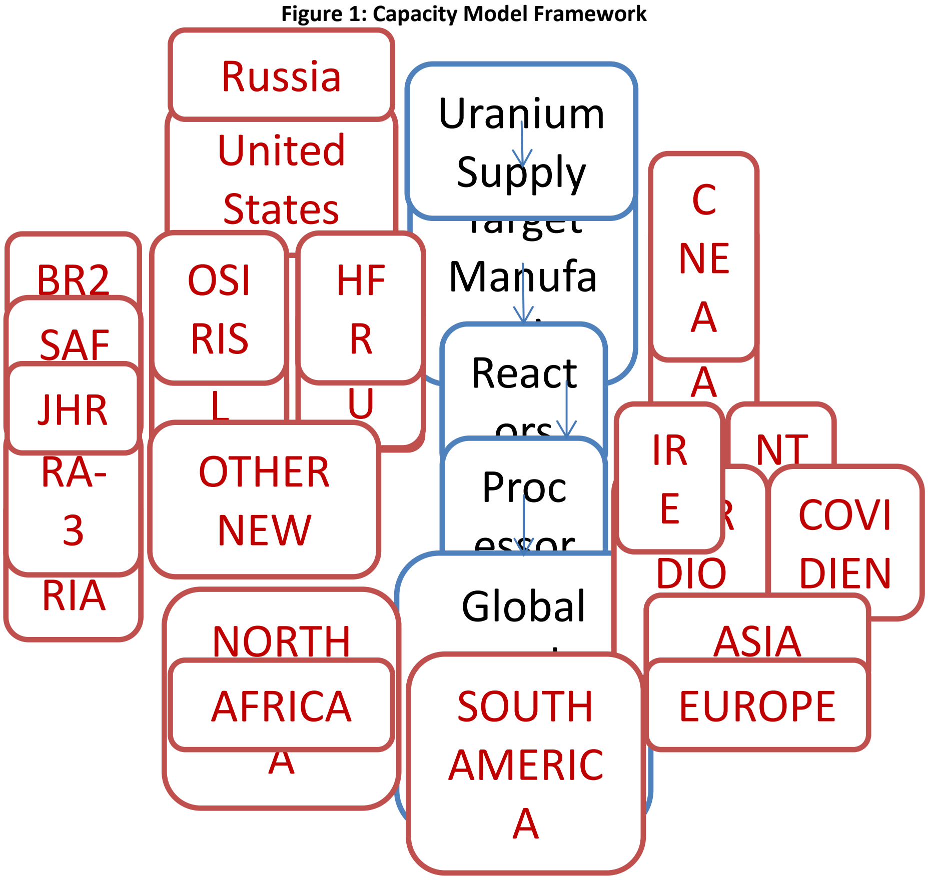
**3. The Capacity and Cost Model Frameworks and Important Impact Elements**

In order to be able to assess the economic and market impacts of converting to LEU targets for producing $^{99}$Mo, it is necessary to have a model of the global supply chain. Once the model is developed and a reference case established, we can assess the expected impacts on the reference case. As noted above, two models will be developed to assess the impacts: one to assess the capacity impacts and one to assess the cost impacts. The model frameworks for these two models will be described below.

The capacity model is intended to provide a reasonable description of the capacity and product flows and availability for the $^{99}$Mo global supply chain. This model will allow for a time-based assessment of the impacts of conversion on the quantities of $^{99}$Mo that can be supplied during and after conversion.

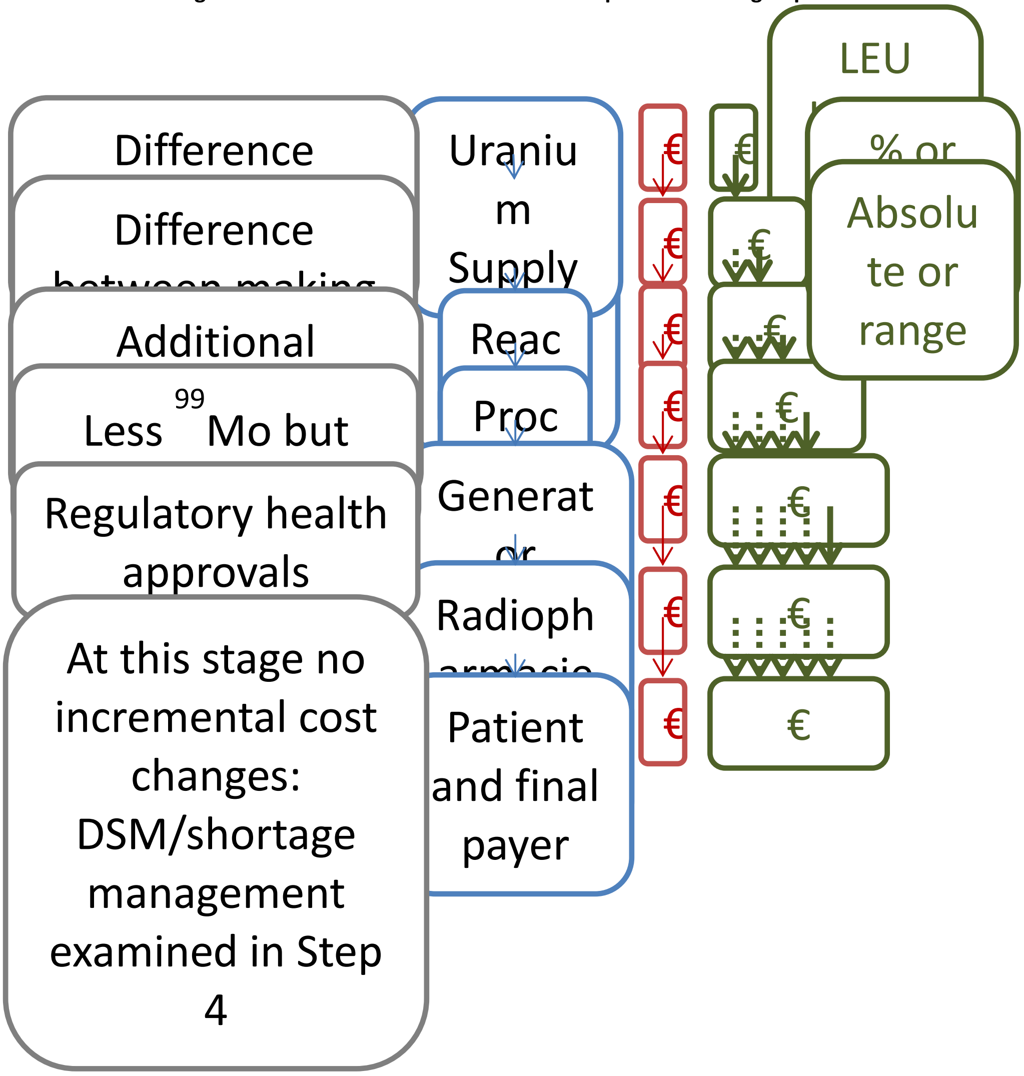
The model will look at the capacity from uranium supply to global and regional markets (see Figure 1). Individual supply chain participants will be included in the model to allow for an assessment of different impacts at different facilities and the impact that may have on downstream players, including regional markets. If it is not possible to have data on regional distribution for commercially confidential reasons, the model will be able to report on the capacity impact expected on the global market.

**Figure 1: Capacity Model Framework**




The cost model is based on the model developed for the HLG-MR's *The Supply of Medical Radioisotopes: An Economic Study of the Molybdenum-99 Supply Chain*. The model will look at the cost of $^{99}$Mo and $^{99m}$Tc through the entire supply chain (from uranium supply to the patient and final payer) by deriving a levelised unit cost of $^{99}$Mo (LUCM) at each stage of the supply chain (see Figure 2).

**Figure 2: Cost Model Framework and Example of Assessing Impacts**

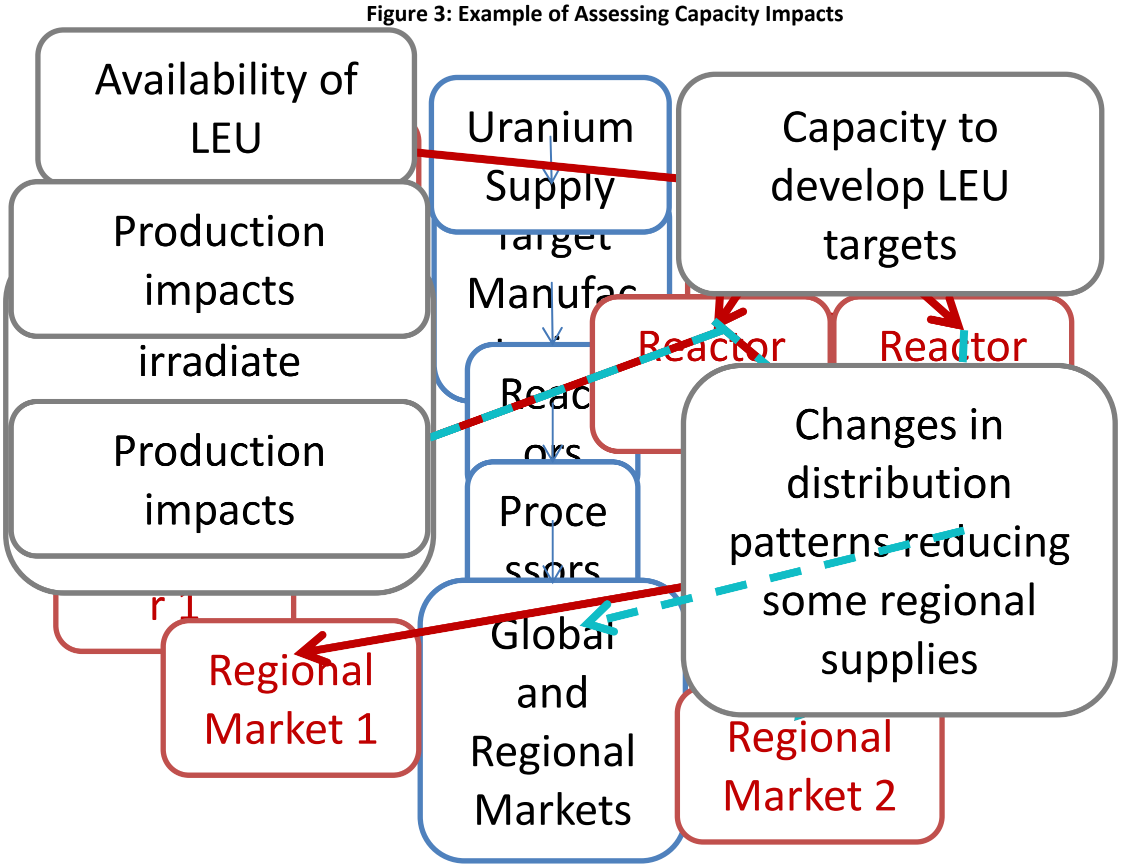



The cost model will include individual supply chain participants, down to and including the processing stage. This will allow for the application of different scenarios within the model, such as differences on infrastructure needs. Since the goal is to see the relative change among supply chain costs and the final payer costs, the starting scenario for each individual participant will be the developed HEU reference scenario.

Both of these model frameworks will be used to assess the impacts of the important elements affecting capacity and costs. As shown in the examples in Figure 3 for the capacity model and Figure 2 for the cost model, the various important impacts will be identified and the degree of the impact (based on experience or reasonable expectations) will be applied to the developed reference cases. From there, the impact will be traced along the supply chain to find the impact on the amount of product reaching the market and the cost to the final payer, respectively. The capacity model will provide results on an annual basis, while the cost model will provide differences in costs based on the reference case and the fully converted case. For the latter model, the project will also identify those costs related to LEU conversion in order to be able to suggest policy options for supporting those costs (Part C of the project).

Overall results will be discussed in the final report. Individual facility costs or capacity impacts will not be directly reported to ensure that the NEA respects the commercial confidential nature of supply chain companies.

**Figure 3: Example of Assessing Capacity Impacts**




At the first workshop on the project, held on 22-23 November 2011, meeting participants discussed the model frameworks and agreed on their general acceptance, suggesting some issues to be aware of moving forward. For example, it was noted that good data is very important to ensure that the results of the modelling will be reasonably accurate.

In addition, participants discussed an extensive list of possible capacity and cost impacts, identifying those impacts that were the most likely to have significant impacts, those where the impacts would be important if they were to occur but they would likely not occur, and those that were not important. The first group of impacts will be modelled; the second group of impacts will be discussed in the final report, but since they are deemed to be unlikely, they will not be modelled. The last group of impacts will be discarded from further consideration within the project.

From the input received during the workshop, it appears that the major areas where direct impacts will be expected are the reactor and processor stages. On the capacity question, the major important impacts identified were related to the fact that there is less uranium-235 in each target and thus less $^{99}$Mo produced during the irradiation and processing stages. In addition, there are expected important impacts related to the time required for regulatory approvals at the processing stage, which can impact the available processing capacity (as some would be used for seeking regulatory approvals and thus not available for normal production). There is also a concern related to the reduction of available outage reserve capacity at both the reactors and processing facilities. There were also a number of capacity impact elements that were identified as important but not likely.

On the cost question, the major impact elements identified were related to the expected need to irradiate and process additional targets. For example, there are expected impacts from having to develop and purchase new LEU targets, and transport additional targets between reactors and processors. In addition, there are expected impacts from the costs of developing new infrastructure for waste management at the processing stage. Participants also indicated that they expect that seeking regulatory approvals at reactors and processors for the various changes necessary will have an important cost impact. There were also a number of cost impact elements that were identified as important but not likely.

The next steps of the project are to build on the preliminary discussions that occurred at the workshop on the degree of the important impacts. The NEA will hold bilateral discussions with many members of the supply chain to obtain more fulsome impact data. This data is essential to ensure that the results from the two models will be accurate, credible, and informative. In addition, the NEA will seek input from stakeholders on various scenarios related to the timing of conversion. Once this information is obtained, the NEA will be able to run the various scenarios and determine the cost and capacity impacts, based on the assumptions under tasks 1-3 of Part A of the project. The future stages of the project will follow.

**4. Conclusion**

This NEA project will draw on the experience and expertise of the supply chain to determine the expected impacts of conversion to using LEU targets for $^{99}$Mo production on the capacity to produce $^{99}$Mo/$^{99m}$Tc for the medical community and the expected cost difference between $^{99m}$Tc produced from HEU-based and LEU-based $^{99}$Mo. This project seeks to address a gap in current knowledge, which will allow for the development of policy recommendations to address any possible impacts during and after the conversion process. The project is in its early stages and will be completed by June 2013.