August 2012

A Supply and Demand Update of the Molybdenum-99 Market

Introduction

Medical diagnostic imaging techniques using technetium-99m account for roughly 80% of all nuclear medicine procedures, representing over 30 million examinations worldwide every year. Disruptions in the supply chain of these medical isotopes – which have half-lives of 66 hours for molybedenum-99 (^{99}Mo) and 6 hours for its daughter isotope, technetium-99m (^{99m}Tc), and thus must be produced continually – can lead to cancellations or delays in important medical testing services. Unfortunately, supply reliability has declined over the past decade due to unexpected or extended shutdowns at the few ageing ^{99}Mo-producing research reactor and processing facilities. These shutdowns have created global supply shortages.

In 2011, the OECD Nuclear Energy Agency (NEA), along with its High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR), released a report that presents the reasons behind the lack of infrastructure that led to global supply shortages and a policy approach to encourage long-term medical isotope supply security. In that report, *The Supply of Medical Radioisotopes: The Path to Reliability*, the NEA also provides potential futures of supply and demand out to 2030[1].

Since the release of *The Path* there have been a number of changes in the market and therefore this document provides an update on the 2011 supply and demand situation. This update is based on information provided to the NEA by members of the HLG-MR and other key stakeholders.

Demand update

In 2011, the NEA released an assessment of future demand for ^{99}Mo/^{99m}Tc out to 2030 (OECD-NEA, 2011b). The future demand scenario was based on data from a global survey and an assessment of that data by an expert advisory group.

Since 2011, it has become clear that the current demand for ^{99}Mo is no longer 12 000 6-day curies per week[2]. This reduction in demand stems from a number of changes that occurred as a result of the 2009-2010 supply shortages, including: better use of available ^{99}Mo/^{99m}Tc, more efficient elution of ^{99}Mo generators, substitute diagnostic tests/isotopes, etc. Based on current market practices, market participants have put the current demand at between 9 500 and 10 000 6-day curies per week.

1. The future scenarios presented by the NEA, including in this report, should not be construed as a prediction, forecast or expectation of which projects will proceed; the scenarios are entirely meant to be illustrative of possible future situations, including where some potential projects do not proceed.
2. A 6-day curie is the measurement of the remaining radioactivity of ^{99}Mo 6-days after it leaves the processors facility (End of Processing).

The NEA has thus revised its demand scenarios to reflect the updated estimate of current demand as 10 000 6-day ^{99}Mo curies from processors. However, the NEA has maintained the expected demand growth rate out to 2030 presented in the 2011 study[3].

An additional change from the future demand scenario presented in *The Path* report is the treatment of the need for outage reserve capacity (ORC)[4]. This update treats ORC as effectively increasing demand for irradiation and processor capacity, as this capacity is required to be "set-aside" in order to ensure security of supply. As a result, there is a range presented for demand based on the NEA demand study, from a situation where no ORC is demanded up to high ORC requirements[5]. This results in current demand with high ORC requirements being equal to approximately 13 300 6-day curies per week.

Supply update

Since the 2011 *Path* document, the NEA has updated the list of current and new potential ^{99}Mo irradiation and processing projects. Based on the most recent information available, the update includes: revisions to production start/end dates, additional potential projects and impacts of converting to using low enriched uranium targets for ^{99}Mo production. Appendix 1 provides the full list of current and potential ^{99}Mo-producing irradiators and processors, along with the status of the projects as of June 2012.

Potential future scenarios of supply and demand

The potential supply presented below is based on the data presented in Appendix 1, with a caveat for current irradiators and processors. Appendix 1 provides the present available normal capacity for current supplying irradiators and processors, and the project at the Russian Research Institute of Atomic Reactors (RIAR), based on their current targetry (low or highly enriched uranium). The supply scenarios presented in this document use capacity and production numbers assuming that the target conversion plans of the various irradiators and processors proceed as expected. As a result, current irradiators (and the RIAR project) have capacity values as presented in the Appendix until they convert to LEU targets. Once converted, the capacity values used account for an expected reduction in capacity under the low impact and high impact scenarios used in the modelling of the impact of converting from high to low enriched uranium targets and associated processing. Where a shutdown is required for the conversion process, this has been included in the future scenarios. Additional information on the impacts of target conversion is available in the forthcoming NEA report, *The Supply of Medical Radioisotopes: Market Impacts of Converting to Low-Enriched Uranium Targets for Medical Isotope Production.*

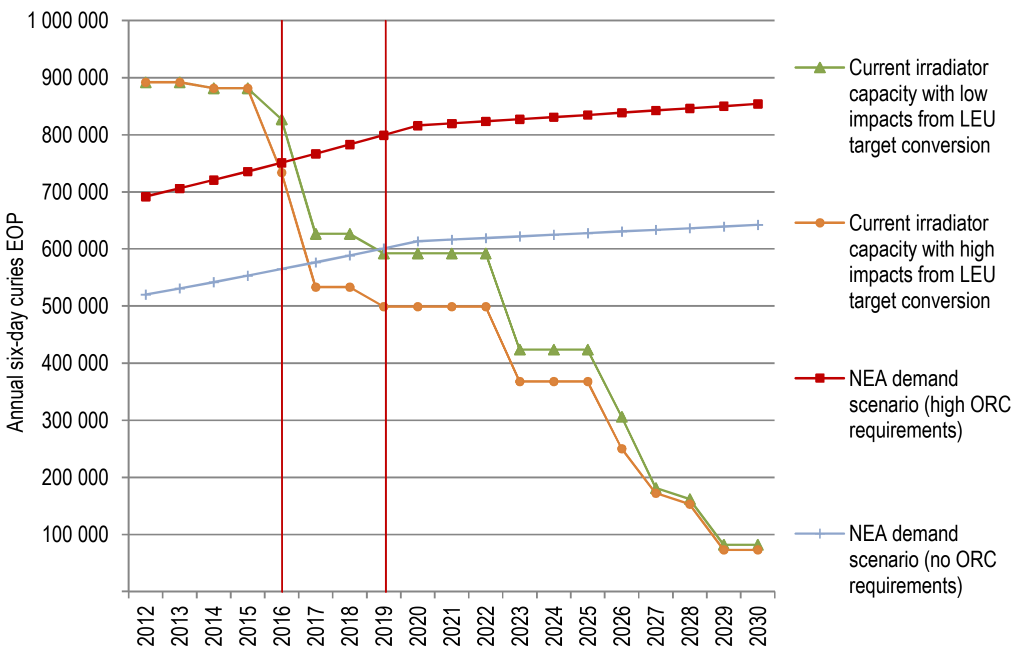
3. The 2011 demand study was focused on determining the growth rate and thus its findings should not be affected by the change of the starting point from which growth is measured. The starting point (in 2011) should have been revised from 12 000 but data was not available at that time.
4. Outage reserve capacity is required to ensure a reliable supply chain by providing back-up irradiation and/or processing capacity that can be called upon in the event of an unexpected shutdown (see OECD-NEA, 2011a for more information).
5. The high ORC requirement is based on a derived model that showed that a system with somewhat effective, but not perfectly ideal, co-ordination with a large reactor in the fleet could maintain necessary ORC levels if each reactor kept, on average, 33% of their capacity as ORC when they operate; this translates into an annual "peak" capacity of about 200% of demand. A derived model with more perfect co-ordination and more equal sized reactors had the ability to maintain ORC levels if each producing reactor kept 17% of its capacity as ORC (low ORC requirement, within the demand range presented). More information will be available in a forthcoming guidance document on ORC being developed by the NEA.

Irradiation Capacity

As has been pointed out in previous NEA studies, the current fleet of irradiators is ageing and many are expected to stop irradiating targets for ^{99}Mo production within the decade. Figure 1 shows the supply and demand future based on the current fleet of irradiators. It is clear that the expected exit of the NRU and OSIRIS reactors from the supply chain in 2016 and 2018 will drastically reduce the available capacity. In addition, the expected conversion to LEU targets in 2015 at most of the existing irradiators will reduce available capacity from the current fleet. Within the ranges presented for supply and demand with the current fleet, shortages could be seen as early as 2016, or by 2019, depending on the actual impact of converting to LEU targets and the demand required.

It should be noted that the timelines for some current irradiators include an assumption that licence extensions will be provided. However, these licence extensions may require some refurbishments in the research reactor and the decision to proceed with those investments may be subject to the economic conditions that prevail in the market at that time. If the decision is to not proceed with the necessary refurbishments, the values in later years would be lower than presented. This highlights a key reason for the need to change the economic situation in the supply chain – to ensure the continued operation of current irradiators.

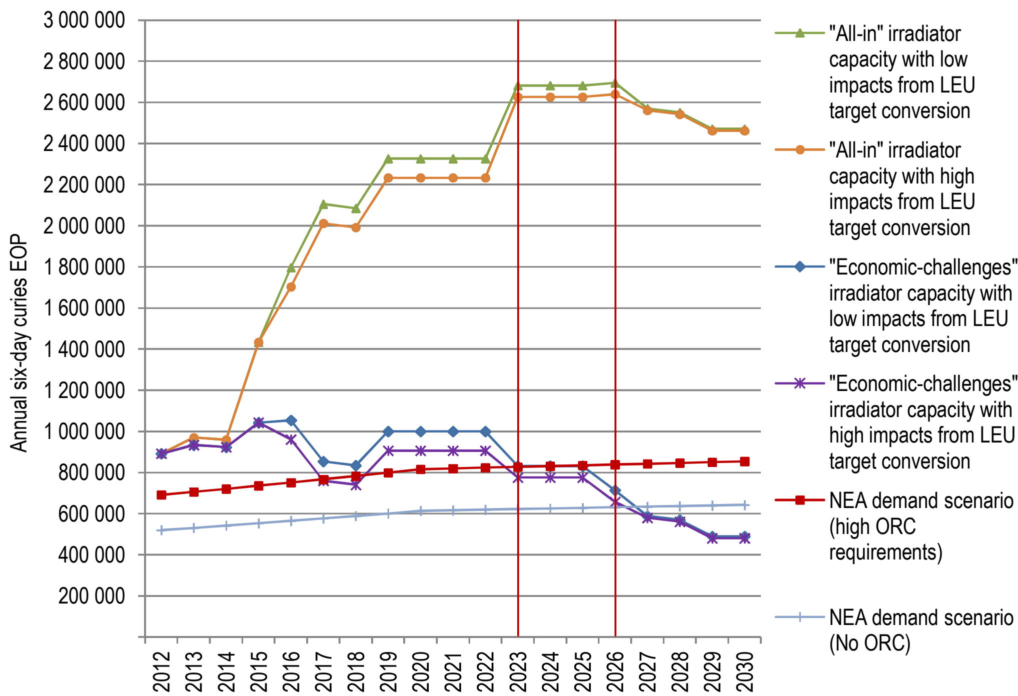
Figure 1. Current irradiator capacity v. demand potential future



As is clear in Appendix 1, there are many potential irradiator projects at various stages of development. Some of these projects are very well advanced, while others are in the proposal or design phase or are seeking financing or other approvals before actually advancing to construction. Figure 2 presents two future situations for current and potential irradiator projects: an “all-in” situation (which includes all current and potential projects) and an economic-challenges situation (explained below). For both of these scenarios, capacity is presented for high and low impacts from LEU-target conversion.

The all-in situation appears to be very promising for future irradiation capacity, with available capacity being more than 300 percent of demand. However, the situation includes all potential projects which have been publicly announced without any validation or assessment of the likelihood of these projects actually being successful. As with all infrastructure development *not all of the projects that are planned will proceed*. Many of the projects may not proceed as a result of the current economic situation in the ^{99}Mo supply chain, because of technological or regulatory challenges that hinder the development of the project or because of the increased competition that would result if all the projects were to enter the market.

Figure 2. Current and potential new irradiator capacity[6] v. demand potential futures



Recognising this reality, the second situation in the figure (economic challenges) shows only those irradiation projects that can proceed in the absence of commercial funding. This situation is expected if the economic conditions in the ^{99}Mo supply chain do not improve from the current economically unsustainable situation that is described in previous NEA reports (OECD-NEA, 2011a and OECD-NEA, 2010).

It should be noted that, based on input from market participants[7], the NEA understands that the uneconomic situation described in the NEA *Economic Study of the Molybenum-99 Supply Chain* continues today. While some irradiators are moving to full-cost recovery (as indicated to be necessary for long-term supply security; for the full HLG-MR policy approach see OECD-NEA, 2011a), it appears that others are not. It has been

6. The total irradiators low and high impact scenarios represent the all-in situation, where all the potential projects proceed. It is clear that not all of the projects that are planned will proceed. The economic-challenges scenario recognises this reality, imposing an economic restriction on planned projects.

7. The information included in this paragraph has not been independently verified by the NEA or another third party and therefore should be taken as anecdotal only. The NEA is currently undertaking a review of the progress of the supply chain towards implementation of the HLG-MR policy approach; results of that review are expected to be released in early 2013.

indicated to the NEA that prices for bulk ^{99}Mo in some cases have apparently declined to unsustainable levels since the shortage period. This past year there have already been two potential project cancellations that indicated that supply chain economics and the related business case were not sufficient to proceed at this time: the GE-Hitachi project and the Dedicated Isotope Production Reactor (DIPR) in South Africa.

Under the economic-challenges situation only the following irradiation sources are included: current reactors[8]; FRM-II; INR; RIAR; KOREA; CARR; BMR; and RA-10. All the other potential projects identified in Appendix 1 are assumed to not proceed under the economic-challenges situation.[9]

The two scenarios presented in Figure 2 represent possible extremes in the future supply of ^{99}Mo. The "all-in" may be optimistic and the "economic-challenges" pessimistic. However, they are provided to illustrate the range of possible outcomes and, again, emphasise that the market does need to change to a sustainable economic structure to ensure supply reliability for the long term. Figure 2 shows that if the economic situation in the supply chain does not improve, the global supply chain will be facing long-term shortages of irradiation capacity as early as 2023, and definitely by 2026, depending on the actual demand within the possible range. This reiterates the concern of previous reports that the very positive outlook of the "all-in" situation hides a possible reality of long-term shortages as a result of the underlying unsustainable economic model of the supply chain.

Processor production

While irradiation capacity is essential for ^{99}Mo production, the future supply and demand scenarios for processor production are more indicative of potential supply, as they recognise the necessary coupling of irradiation and processing infrastructure; where one is available without the other, the potential capacity cannot be used. This was the case in the 2009-2010 shortages, when processing capacity in Canada could not be used as the NRU reactor in Canada was shut down, and at the same time available irradiator capacity in Europe could not be completely used as there was not sufficient processing capacity to offset the production losses in Canada.

While processing *capacity* seems to be sufficient out to 2030 under all situations, processing *production* is not sufficient under some of the situations modelled. Two principal reasons for this insufficiency are the lack of sufficient irradiator capacity under certain situations and regional limitations of processors in relation to the location of new irradiation capacity.

In Figure 3, the supply of bulk ^{99}Mo from current processors is shown to be insufficient from 2017 onwards. This long-term shortfall is a result of insufficient irradiator and related processing capacity from the current fleet. This situation assumes that new irradiator capacity comes on line, but current processing capacity is insufficient to be able to use the increased irradiator capacity when location requirements are taken into account.

Even under a hypothetical situation of no LEU-target conversion (not shown here), long-term shortfalls could occur from 2017 onwards. This point demonstrates the fact that the major concern related to long-term ^{99}Mo/^{99m}Tc supply security is not principally

8. While all current reactors continue operation under this scenario, it is possible that some may have to stop production at some point in the future if the economic situation does not improve as they receive no or limited government funding. This possibility is not modelled in the scenarios.
9. The NEA also modelled a technology-challenges scenario, where new technologies and new projects face a higher risk and thus some do not proceed. Under this scenario, supply was greater than demand over the entire time period.

related to LEU-target conversion but rather is related to the underlying economic problems in the supply chain that hinder new infrastructure investment.

Figure 3. Current processor production v. demand potential future

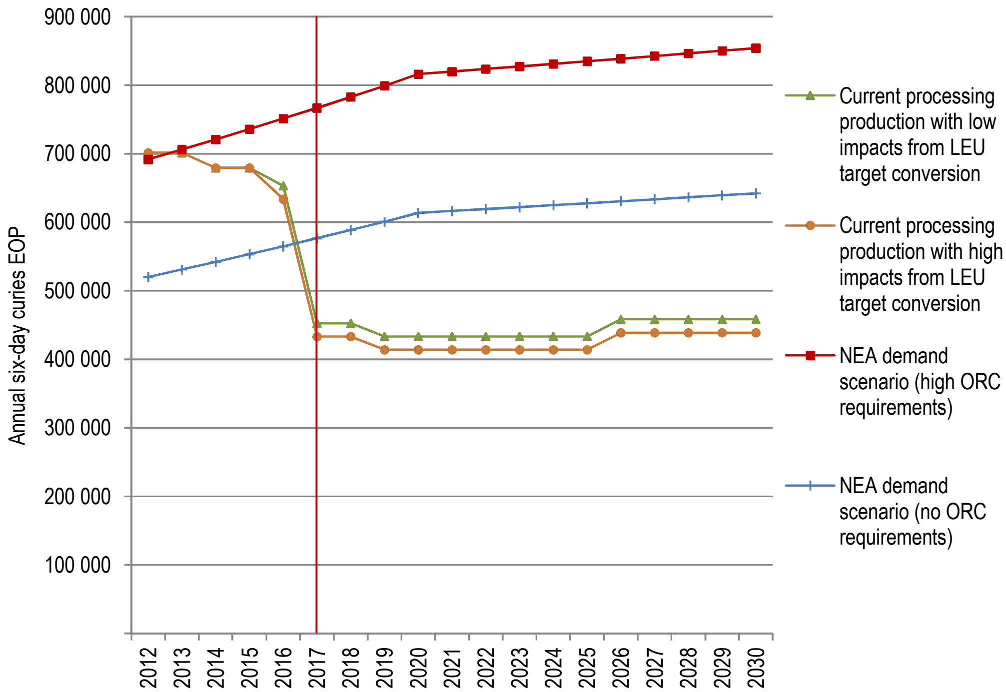


Figure 4 presents two future situations for current and potential processing projects: an "all-in" situation (which includes all current and potential projects) and an economic-challenges situation. For both of these scenarios, production is presented accounting for high and low expected impacts from LEU-target conversion.

The all-in situation for potential processor production, as with irradiation capacity, appears to be very promising for long-term supply security, with absolute potential production (from all new irradiators and all new related processing facilities) approximately 250 percent of demand. However, the situation includes all potential projects which have been publicly announced without any validation or assessment of the likelihood of these projects actually being successful. As noted earlier, not all of the planned projects are actually expected to proceed given economic, technological and/or regulatory challenges. As a result, the all-in situation presents an overly optimistic scenario that likely will not be realised.

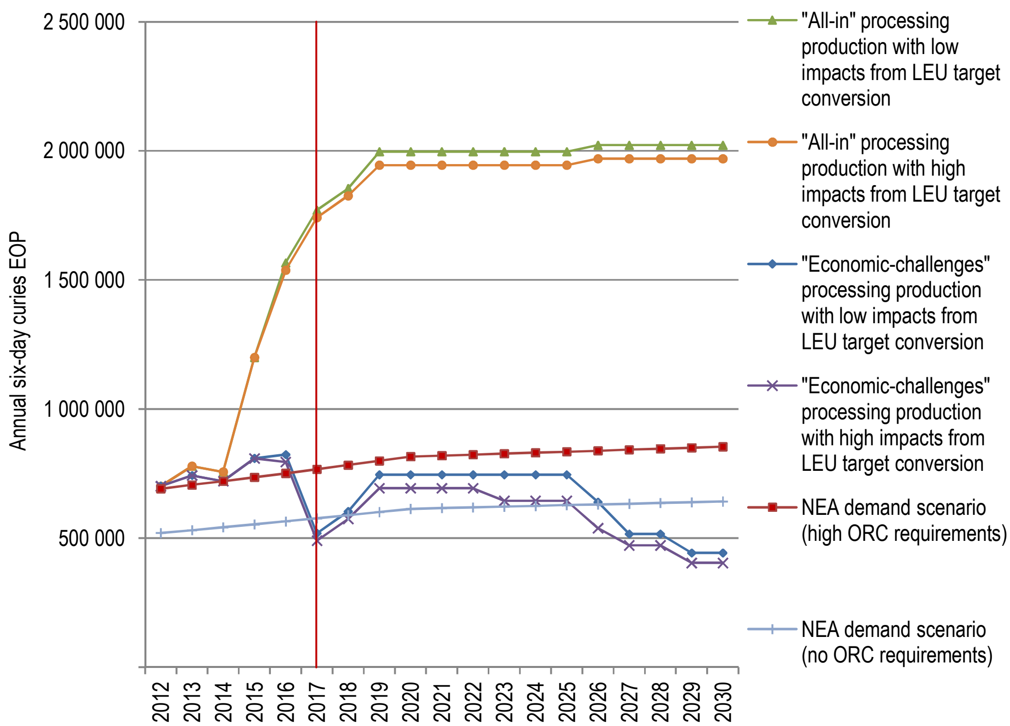
The second situation presented in Figure 4 is the economic-challenges situation[10]. This situation shows only those projects that can proceed in the absence of commercial funding, both irradiation (discussed in the previous section) and processing projects[11].

10. The NEA also modelled a technology-challenges scenario, where new technologies and new projects face a higher risk and thus some do not proceed. Under this scenario, supply was greater than demand over the entire time period, with two tight periods around 2014 and 2017.

11. Again, the economic-challenges situation for processors assumes that all current processors continue operation; however, it is possible that some may have to stop production at some point in the future if the economic situation does not improve as they rely on commercial funding. This possibility is not modelled.

This situation shows the potentially available supply of bulk ^{99}Mo if the economic conditions in the supply chain do not improve from the current economically unsustainable situation that is described in previous NEA reports (OECD-NEA, 2011a and OECD-NEA, 2010). Recognising the economic situation that reportedly exists today, this economic-challenges situation appears to be a serious possible future outcome.

Figure 4. Current and potential new processing production[12] v. demand potential futures



As above, the two scenarios presented in Figure 4 represent possible extremes in the future supply of ^{99}Mo. The "all-in" may be optimistic and the "economic-challenges" pessimistic. However, they are provided to illustrate the range of possible outcomes and, again, emphasise that supply does need the market to change to a sustainable economic structure to ensure supply reliability for the long term. Figure 4 shows that if the economic situation does not improve, the global supply chain could be facing long-term supply shortages by 2026. Shortages could arrive earlier (2017) under demand with a high outage reserve capacity requirement. This reiterates the concern of previous reports that the very positive outlook of the "all-in" situation hides a possible reality of long-term shortages if potential projects do not proceed because of economic barriers.

It must be noted that under an economic-challenges situation where future LEU-target conversion does not occur, there is still a potential shortage expected in 2017 but the supply of bulk ^{99}Mo then increases above the high ORC demand curve until 2026. Under this situation, definite long-term shortages occur in 2027, when the no-conversion scenario drops below the no ORC demand curve.

12. The total processing low and high impact scenarios represent the *all-in situation*, where all the potential projects proceed. It is clear that not all of the projects that are planned will proceed. The economic-challenges scenario recognises this reality, imposing an economic restriction on planned projects.

Conclusion

This presentation of supply and demand future scenarios for the ^{99}Mo market revises previous NEA future scenarios based on new data and target conversion commitments from the supply chain. The update, unfortunately, does not present a more optimistic future scenario than previous presentations – the concern around the uneconomic situation of the supply chain continues to dominate the potential for new projects. This results in the potential for long-term shortages within the decade. However, there are a number of potential projects that are in various stages of development. If the economics were to change and some of these projects proceed, the long-term supply of ^{99}Mo/^{99m}Tc should be reliable. This points to the need to implement the HLG-MR policy approach (OECD-NEA, 2011a). The supply chain cannot become complacent now that current supply is sufficient to meet demand, as this situation could very quickly change – leading to consistent long-term shortages of ^{99m}Tc and reducing the availability of important nuclear medicine diagnostic examinations for patients around the world.

References/further reading

Available at www.oecd-nea.org/med-radio:

OECD-NEA (forthcoming), The Supply of Medical Radioisotopes: Market Impacts of Converting to Low-Enriched Uranium Targets for Medical Isotope Production, OECD, Paris.

OECD-NEA (2011a), *The Supply of Medical Radioisotopes: the Path to Reliability*, OECD, Paris. ISBN 978-92-64-99164-4.

OECD-NEA (2011b), The Supply of Medical Radioisotopes: An Assessment of Long-term Global Demand for Technetium-99m, OECD, Paris.

OECD-NEA (2010), *The Supply of Medical Radioisotopes: An Economic Study of the Molybenum-99 Supply Chain*, OECD, Paris. ISBN 978-92-64-99149-1.

Appendix 1

Table 1. Current irradiators

Reactor	Targets	Normal operating days	Normal available capacity per week (6-day Ci)[1]	Potential annual production (6-day Ci)[2]	Estimated stop production date
BR-2	HEU	140	7 800	156 000	2026
HFR	HEU	280	4 680	187 200	2022
LVR-15	HEU	200	2 800	80 000	2028
MARIA	HEU	165	1 920	42 500	2030
NRU	HEU	300	4 680	200 600	2016
OPAL	LEU	290	1 000	41 450	>2030
OSIRIS	HEU	200	1 200	34 300	2018
RA-3	LEU	336	400	19 200	2027
SAFARI-1	HEU[3]/LEU	305	3 000	130 700	2025

1. What is possible under normal operations, without major changes to the reactor or sacrifices to other irradiation missions.

2. Based on operating days and normal available capacity – not necessarily what is actually produced currently, rounded.

3. NTP HEU targets are enriched to approximately 45%, compared to the industry standard of 90-93%.

Table 2. Current processors

Processor	Targets	Capacity per week (6-d Ci)	Available annual capacity (6-d Ci)[1]	Expected date of conversion to LEU targets
AECL/NORDION	HEU	7 200	374 400	Not expected[2]
ANSTO HEALTH	LEU	1 000	52 000	Started as LEU
CNEA	LEU	900	46 800	Converted
COVIDIEN	HEU	3 500	182 000	2015
IRE	HEU	2 500	130 000	2015
NTP	HEU[3]/LEU	3 000	156 000	2013[4]

1. Actual production is often less, as processing capacity is technically available 52 weeks while irradiated targets are not delivered 52 weeks of the year for all processors. When determining processor production, irradiator limitations are taken into account where they exist. This may have the effect of some processing capacity not being fully used if there is not sufficient irradiator capacity to supply the processor with irradiated product.

2. The government of Canada has announced that it will not produce ^{99}Mo at the NRU reactor after 2016, therefore they do not expect to convert to using LEU targets for the production of ^{99}Mo.

3. NTP HEU targets are enriched to approximately 45%, compared to the industry standard of 90-93%.

4. NTP can already produce LEU-based ^{99}Mo but does not expect 100% production from LEU targets until 2013, as their customers required time to obtain the necessary health regulatory approvals.

Table 3. Potential irradiators

Irradiation source	Targets/technology[1]	Expected operating days	Expected normal available capacity per week (6-d Ci)[2]	Potential annual production (6-day Ci)[3]	Estimated first full year of production[4]	Project status (19 June 2012)
NORTHSTAR[5]/MURR (United States)	Non-fissile in CRR	336	750/3 000	36 000/144 000	2013/2016	Phase 1 Nearing completion/ Phase 2 Seeking financing
RIAR[6] (Russian Federation)	HEU in CRR	365	800/2 000	41 700/104 300	2013/2015	Phase 1 Nearing completion/ Phase 2 Under development
B&W MIPS (United States)	LEU solution in AHR	336	4 400	211 200	2015	Preliminary design and applications underway
CHINA ADVANCED RR	LEU in CRR	180	1 000	25 700	2015	Under construction
INR, Pitesti (Romania)	LEU in CRR	250	900	31 200	2015	Proposal
NORTHSTAR[5] (United States)	Non-fissile from LINAC	336	3 000	144 000	2015	Construction not yet started
FRM-II (Germany)	LEU in CRR	240	1 950	65 950	2016	Infrastructure installed, pending LEU target design
MORGRIDGE/SHINE (United States)	LEU solution with DTA and SAHR	336	3 000	144 000	2016	Preliminary design and applications underway
OPAL[7] (Australia)	LEU in CRR	290	3 400	140 850	2016	Available, pending processing capacity
AMIC (United States)	LEU solution with HA-HWS	336	3 000	144 000	2017	Seeking financing
Coqui (United States)	LEU in CRR	365	7 000	365 000	2017	Seeking financing
Brazil MR	LEU in CRR	290	1 000	41 450	2018	Preliminary design
KOREA	LEU in CRR	300	1 000	42 850	2018	Preliminary design
JULES HOROWITZ RR (France)	LEU in CRR	220	2 400	75 450	2019	Under construction
RA-10 (Argentina)	LEU in CRR	336	2 000	96 000	2019	Preliminary design
PALLAS (Netherlands)	LEU in CRR	300	7 300	312 000	2023	Design phase, additional funding required
MYRRHA (Belgium)	LEU in ADS	238	6 250	212 150	2023	Design phase, additional funding required
SAFARI-II (South Africa)	LEU in CRR	305	3 000	130 700	2026	Feasibility study underway

1. CRR = Conventional Research Reactor; AHR = Aqueous Homogeneous Reactor; LINAC = Linear Accelerators; DTA = Deuterium-Tritium Accelerator; SAHR = Subcritical Aqueous Homogeneous Reactor; HA-HWS = Hybrid Accelerator – Heavy Water System; ADS = Accelerator Driven System Research Reactor.

2. What is possible under normal operations, without major changes to the reactor or sacrifices to other irradiation missions.

3. Based on expected operating days and normal available capacity presented, rounded.

4. Assumed full-scale production starts one year after commissioning unless available information indicates differently, estimated by project proponents.

5. Produces low-specific activity ^{99}Mo that requires use of Northstar's generator to produce ^{99m}Tc.

6. The project includes three reactors, two of which will be used to irradiate for continuous ^{99}Mo production, with the third being a back-up.

7. New production as a result of new processing capacity, "replaces" OPAL current capacity.

Table 4. Potential processors

Processor	Targets and (expected date of conversion)	Assumed expected available capacity per week (6-day Ci)[1]	Expected available annual capacity (6-day Ci)[2]	Estimated first full year of production[3]	Project status (19 June 2012)
NORTHSTAR/MURR	Non-fissile	750/3 000	36 000/144 000	2013/2016	Nearing completion/ seeking financing
RIAR/NORDION	HEU (2018)	800/2 000	41 700 / 104 300	2013/2015	Nearing completion/ under development
B&W MIPS	LEU solution	4 400	211 200	2015	Preliminary design and applications underway
CHINA ADVANCED RR	LEU	1 000	24 700	2015	Under construction
NORTHSTAR (LINAC)	Non-fissile	3 000	144 000	2015	Construction not started yet
ANSTO: MEGA MOLY[4]	LEU	3 400	176 800	2016	Design phase
MARIA: MOLYBDENUM 2010	LEU	1 000	52 000	2016	Seeking financing
MORGRIDGE/SHINE	LEU solution	3 000	144 000	2016	Preliminary design and applications underway
AMIC	LEU solution	3 000	144 000	2017	Seeking financing
Coqui	LEU	7 000	365 000	2017	Seeking financing
BMR	LEU	1 000	41 450	2018	Preliminary design
KOREA	LEU	1 000	42 850	2018	Preliminary design
RA-10	LEU	2 000	150 800	2018	Preliminary design

1. Derived assuming an ability to process irradiated sources linked with the project, unless additional information available.

2. Based on ability to process irradiated sources linked with the project, unless additional information available, rounded; in some cases actual production may be less as processors may not have access to irradiated sources 52 weeks of the year. When determining expected processor production, irradiator limitations are taken into account where they may exist. This may have the effect of some processing capacity not being fully used if there is not sufficient irradiator capacity to supply the processor with irradiated product.

3. Dates based on discussions with supply chain participants as well as publicly available statements, presentations and reporting.

4. Replaces current ANSTO processing capacity.