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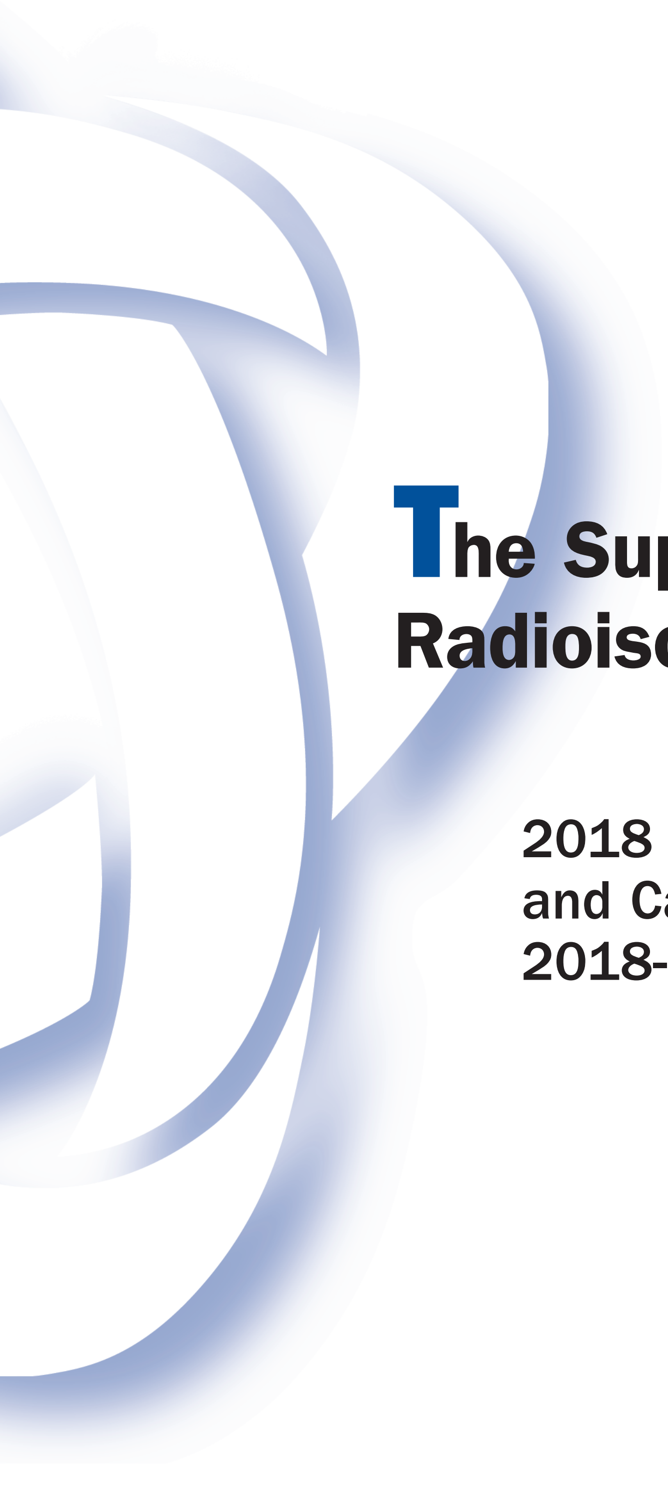

The Supply of Medical Radioisotopes

2018 Medical Isotope Demand and Capacity Projection for the 2018-2023 Period

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Acknowledgements

This report would not have been possible without the contributions of a large number of supply chain participants and stakeholders, including major reactor operators and processors, generator manufacturers, nuclear pharmacies, governments and associations representing nuclear medicine professionals, nuclear pharmacies, hospitals and industry.

The OECD Nuclear Energy Agency (NEA) greatly appreciates the important information provided confidentially by supply chain participants to the NEA to support the work of the High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR). The information on molybdenum-99 (^{99}Mo)/technetium-99m (^{99m}Tc) production capacity and facility utilisation supports the analysis of demand and the creation of capacity projections for the 2018-2023 period. These projections are intended to help policy makers, producers and other stakeholders take decisions that lead to appropriate actions to ensure the economically sustainable, long-term, secure supply of the key medical isotopes ^{99}Mo and its decay product, ^{99m}Tc.

This report was written by Mr Kevin Charlton of the NEA Division of Nuclear Technology Development and Economics. Detailed review, comments and suggestions were provided by members of the HLG-MR.

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List of abbreviations and acronyms

ANM	ANSTO Nuclear Medicine
ANSTO	Australian Nuclear Science and Technology Organisation
CNL	Canadian Nuclear Laboratories
EOP	End of processing
FCR	Full cost recovery
HEU	High-enriched uranium
HLG-MR	High-level Group on the Security of Supply of Medical Radioisotopes
LEU	Low-enriched uranium
NEA	Nuclear Energy Agency
NRU	National Research Universal
ORC	Outage reserve capacity

Chapter 1. Introduction

Medical diagnostic imaging techniques using technetium-99m (^{99m}Tc) account for approximately 80% of all nuclear medicine procedures, representing 30-40 million examinations worldwide every year. Disruptions in the supply chain of these medical isotopes – which have half-lives of 66 hours for molybdenum-99 (^{99}Mo) and only 6 hours for ^{99m}Tc, and thus must be produced continuously – can lead to cancellations or delays in important medical procedures, with consequent effects on patients and their treatment.

Supply reliability has often been challenged over the past decade due to unexpected shutdowns and extended refurbishment periods at some of the ^{99}Mo-producing research reactors and processing facilities, many of which are relatively old. These shutdowns have at times created conditions for extended global supply shortages (e.g. 2009-2010).

At the request of its member countries, the Nuclear Energy Agency (NEA) became involved in global efforts to ensure an economically sustainable, long-term secure supply of ^{99}Mo/^{99m}Tc. Since June 2009, the NEA and its High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) have examined the causes of supply disruptions and developed a policy approach, including principles and supporting recommendations to address those causes. The NEA has reviewed the global ^{99}Mo demand and supply situation periodically, to highlight future periods of potential supply weakness and to underscore the case for implementing the HLG-MR policy approach in a timely and globally consistent manner.

In 2012, the NEA released a ^{99}Mo supply and demand forecast up to 2030, identifying periods of potential low supply relative to anticipated demand. That 2012 forecast was updated with a report in 2014 that focused on the shorter 2015-2020 period. That report was updated in 2015, in 2016 and then in 2017 with a report, "2017 Medical Isotope Supply Review: ^{99}Mo/^{99m}Tc Market Demand and Production Capacity Projection 2017-2022" (NEA, 2017), with each report focused on a six-year period.

All of the reports since 2014 have identified that substantial delay can occur during the implementation of new projects, even when only looking at a six-year time window. This confirms that trying to project the likely production capacity for a period beyond a six-year window would have little added value.

This report[1] updates the 2017 analysis and focuses on the 2018-2023 period, an important period that follows the planned removal from service of a number of substantial production facilities. In particular, the OSIRIS reactor in France permanently ended operations in late 2015 and the National Research Universal (NRU) reactor in Canada ceased the routine production of ^{99}Mo at the end of October 2016. The NRU reactor then permanently shut down all operations in late March 2018. The processing capacity associated with the NRU had moved to a "hot standby" mode for the period between October 2016 and March 2018, thereby retaining a capability to provide a contingency capacity during that period if justified, the contingency capacity was not used.

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[1] The scenarios presented by the NEA in this report should not be construed as a prediction or forecast of which projects will proceed and when. The scenarios are only meant to be illustrative of possible future situations, whether planned new projects materialise or not.

Although the supply chain was put under substantial stress in mid-November 2017 due to the unplanned outage of the NTP facility (South Africa), the potential NRU reactor contingency capacity capability was not called upon. The NTP facility returned to limited service in late February 2018 with a plan to move stepwise towards a return to full capacity during the first half of 2018. The extent and duration of the NTP outage and reduced capacity period has drawn the total short-term processing capacity below the key NEA demand + 35% outage reserve capacity (ORC) line during the first half of 2018, with the result of a chronic level of supply shortage being experienced in some markets throughout the first quarter of 2018.

Some important progress has been made in recent years

The Curium (the Netherlands) processing facility confirmed conversion to 100% use of low-enriched uranium (LEU) targets in mid-January 2018; with that announcement, well over half of all worldwide ^{99}Mo/^{99m}Tc production has been successfully converted to LEU. Additional conventional reactor capacity and associated processing capacity from existing supply chain members was added during 2016 and 2017. However, some recent capacity reductions have been announced related to reactor operating experience associated with the conversion to LEU targets. This confirms the anticipated effect of some reduction in irradiation efficiency experienced with the use of LEU targets. Curium, however, has not reported a reduction in its total processing capacity.

The introduction of some non-conventional reactor-based ^{99}Mo/^{99m}Tc production had been anticipated in 2017, but this did not occur. However, in early February 2018, marketing approval was granted for the NorthStar RadioGenix system by the US Food and Drug Administration (FDA). That decision allows ^{99}Mo/^{99m}Tc from neutron activated natural molybdenum targets produced in a conventional research reactor to be supplied into the US market from the second quarter of 2018 onwards.

This report presents global irradiation and processing capacity under the same three main capacity scenarios as set out in the 2015, 2016 and 2017 reports. It is intended that it offers a high added value to the international community, and the HLG-MR delegates have emphasised the importance of continuing to produce updates to this report on at least an annual basis. The information in this report should be interpreted in terms of projected future trends and should not be interpreted as actual forecast production values and implementation dates.

Chapter 2. Demand update

In 2011, the NEA released a study with the results of a global survey of future demand for ^{99}Mo/^{99m}Tc (NEA, 2011), based on an assessment by an expert advisory group. The study anticipated ^{99}Mo/^{99m}Tc demand growth up to 2030 in both mature and emerging markets, with stronger growth forecast in emerging markets.

In a subsequent report, "A Supply and Demand Update of the Molybdenum-99 Market" (NEA, 2012a), the NEA estimated global ^{99}Mo demand at 10 000 6-day curies ^{99}Mo per week[1] at end of processing (EOP). This demand was lower than the previous estimate of 12 000 6-day curies ^{99}Mo per week EOP and the difference primarily resulted from a number of changes that occurred in the market as a consequence of the 2009-2010 global supply shortages. Those changes included: better use of available ^{99}Mo/^{99m}Tc, more efficient elution of ^{99m}Tc generators, adjustments to patient scheduling, and some increased use of substitute diagnostic tests/isotopes. Some of those changes continued to be implemented in the market after the end of the 2009-2010 ^{99m}Tc supply shortage.

The April 2014 report, "Medical Isotope Supply in the Future: Production Capacity and Demand Forecast for the ^{99}Mo/^{99m}Tc Market, 2015-2020" (NEA, 2014), used as a starting point the NEA 2012 estimate of 10 000 6-day curies ^{99}Mo EOP per week from processors, but with modified annual demand growth rates of 0.5% for mature markets and 5% for developing markets. This change was based on information provided at that time by supply chain participants.

The August 2015 report, "The Supply of Medical Radioisotopes: 2015 Medical Isotope Supply Review: ^{99}Mo/^{99m}Tc Market Demand and Production Capacity Projection 2015-2020" (NEA, 2015), introduced an adjusted demand estimate of 9 000 6-day curies ^{99}Mo EOP per week from processors. This was based on a new set of data that was collected by the NEA from supply chain participants on capacity utilisation for each operating quarter of the period 2012 to 2014. The data along with the actual operational periods for each facility (e.g. the actual number of operational days) provided useful information, as it included known periods when the supply chain had been stressed due to a number of facilities suffering outage periods at the same time.

The reasons behind that market demand estimate being lower than in earlier reports were not clear. The continuation of some of the measures mentioned previously to increase efficiency of use of ^{99m}Tc at the nuclear pharmacy and in the clinic, combined with some reduction in average injected dose due to some technical improvements in gamma cameras, as well as some procedure protocol changes may have played some role. Also, in a market where full cost recovery (FCR) pricing continues to be implemented in steps along the supply chain, with the result of steadily and substantially increased prices, it would be understandable that efficiency of use of materials was a priority for all supply chain participants who have an objective of minimising costs.

This report builds upon the same approach as the April 2017 report; it is based upon analysis of the same supply chain data set, but now for the period from 2012 to 2017. Estimated market growth rates in this report have been kept unchanged at 0.5% for

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1. A 6-day curie is the measurement of the remaining radioactivity of ^{99}Mo six days after it leaves the processing facility (i.e. at the end of processing – EOP). In International System (SI) Units, 1 Ci is equal to 37 Giga becquerels.

mature markets and 5% for developing markets during the forecast period. At the end of 2014, mature markets were estimated to account for 84% of the global demand for ^{99}Mo/^{99m}Tc, while emerging markets accounted for 16%.

The latest available data has been analysed to determine the level of recent market demand as described above, with reported global utilisation capacity being taken as a surrogate for the demand in the market. The data set is not 100% complete; again in this report, one processor did not provide the requested data. For the purposes of this report, the market demand for ^{99}Mo activity has been held at 9 000 6-day curies ^{99}Mo EOP per week EOP based upon a starting reference time point of the end of 2014. This means that with the growth rates used in this report, the market demand at the beginning of 2018 has increased and is estimated to be approximately 9 400 6-day curies ^{99}Mo per week, a total increase of approximately 4.5% since the end of 2014.

The latest analysis does not fully confirm nor disprove this level of estimated market growth during the period. The latest data for 2017 does however reconfirm that recent global demand for ^{99}Mo is close to a level of 9 400 6-day curies ^{99}Mo EOP per week, with some demand fluctuations seen at a quarterly level.

There is some evidence that the level of production needed to supply the market has increased since the end of routine NRU production in late 2016. The end of NRU production directly resulted in extending supply lines to the large US market, with increased volumes of material delivered from outside North America. The short half-life of ^{99}Mo (66 hours) – the product form that is transported internationally to generator manufacturers – results in approximately 1% of the entire quantity of product shipped being lost through decay for every additional hour of distribution time. This is equivalent to a total 22.3% decay loss during 24 hours of additional distribution time.

Increases in distribution distance and time have indirectly added to the demand for product per week at the EOP time point. As an example, the actual production level at the processor point in the supply chain, at the time point EOP, must increase by 28.7% to offset a 24-hour decay loss sustained in shipping that product for 24 hours of additional distribution time. Likewise, the direct cost of production of the same product distributed for longer transport distances/times also increases proportionally. This is an example of how production capacity may need to increase for ^{99}Mo, without there being an equivalent increase in the end-user demand for the final product.

What capacity level is required to ensure that 99Mo/99mTc demand is met?

The capacity level required to ensure that the market needs for ^{99}Mo/^{99m}Tc are met must include some level of paid outage reserve capacity (ORC). In the HLG-MR policy principles, it was proposed that a processor should hold a sufficient level of paid ORC to replace the largest supplier of irradiated targets in their supply chain. Likewise, participants further down the supply chain should hold similar levels of ORC. This is the so-called (n-1) criterion, that is, the level of ORC required by a customer to ensure that no supply disruption occurs when their largest individual supplier has an unplanned problem.

In fact, there have been occasions over the last few years when, for some participants, the (n-2) criterion (e.g. the ability to replace their two largest suppliers) may have been a more appropriate measure. The actual levels for (n-1) and (n-2) criterion vary for each supply chain participant depending upon the diversity of their own supply chain, and the actual levels of ORC that are required may change as part of a dynamic process, for example when suppliers in different locations enter and exit the market and the supply chain length changes.

As the number of separate supply chain participants has decreased since 2012 and the market share of the remaining participants has increased, it is clear that the general level of risk associated with an (n-1) type supply problem has also increased.

Furthermore, with fewer total supply chain members available, when an (n-1) supply stress situation does occur (as has happened recently), the ability of the remaining suppliers to reschedule and cover all possible supply weaknesses over an extended period is likely to be lower.

In this report, the minimum ORC level recommended to meet demand has been held at the same level as the preceding report, that is, at a level of market demand plus ORC of +35%. Analysis of historical data has shown that the security of supply comes under stress whenever the theoretical maximum available production capacity falls below the level of demand +35% ORC.

Projected potential production capacity in this report is compared to "demand +35% ORC", with the level of demand without ORC also being shown as a reference line. Changes to the market share of the various supply chain members has been reviewed and while the maximum individual market share projected in 2018 is now higher than it was in 2012, the level of change does not justify adjusting the measure "demand + 35% ORC" as being a safe guidance level for an (n-1) supply situation. This statement is made on the clear provision that all of the members of the supply chain are fully implementing paid ORC in an appropriate way.

What changes have there been in overall reserve capacity?

All supply chain participants agree that the principle of holding paid ORC is essential to ensure reliable supply. The need for ORC was amply illustrated in 2013, 2014, 2015 and more recently in late 2017, with unplanned outages occurring at major ^{99}Mo producers during each of those years. On each occasion, these significant outages have tested the ability to ensure reliable supply.

In the earlier years mentioned above, this challenge was largely met by the supply chain using available ORC or perhaps by sourcing other non-contracted reserve capacity on a temporary basis. This resulted in only a small number of limited supply shortages in some countries. The most recent supply stress event that started in mid-November 2017 has been more challenging. This is because the total level of capacity available above the demand +35% ORC level had decreased by late 2017 due to the planned facility closures reported earlier.

Analysis of the theoretical level of total reserve capacity available to the market (total available capacity minus actual utilised capacity) on a quarterly level shows an overall positive trend for the level of total reserve capacity available. This is the case for both the irradiation capacity and processing capacity that was actually available for the period from 2012 until 2017 and also for the projected theoretical reserve capacity available until 2020. This analysis is a combination of actual facility utilisation data and the projection of anticipated reserve capacity based upon the planned operating regimes reported by the existing supply chain participants.

While the overall trends for total reserve capacity of both irradiation and processing capacity are positive, the actual capacity utilisation data from 2012 to 2017 shows some periods of quite significant peaks and troughs. The lowest trough period for available reserve irradiation capacity was in 2Q 2017, while the lowest trough period for available reserve processing capacity was 1Q 2014. 1Q 2014 was a period of substantial unplanned processor outage where the level of shortage experienced was greater than that recently experienced in 2017.

Both irradiation and processing capacity had a sustained trough period starting from 4Q 2016. This trough period was anticipated as it resulted from the planned withdrawal of the NRU Reactor and the associated processing facilities from routine ^{99}Mo production. Overall reserve capacity still remains in the trough period that began in 4Q 2016, but both are projected to resolve during 2018, with reserve irradiation capacity projected to increase from Q2 2018 and reserve processing capacity projected to increase from Q3

2018. In both cases the reserve capacity projected increases to levels above the long-term trend lines for reserve capacity. It should be noted that both projected increases are dependent upon short-term additional capacity entering the market from Australia and upon the level of supply from South Africa returning to historic levels.

Is sufficient Outage Reserve Capacity being held?

It is important to identify that the level of theoretical reserve capacity is not the same thing as contracted paid ORC. As mentioned in previous reports, the NEA has no direct way to measure the actual amount of paid ORC that is held in the supply chain. The actual level of paid ORC is the subject of many commercial agreements, each held between two or more supply chain participants.

It is worth recalling that contracted ORC itself can be provided in a number of ways; these include the holding of additional supply contracts with supply chain members higher up the chain, and/or additional supply contracts held horizontally between supply chain members at the same level within the supply network. Demand-side ORC can also be provided by supply agreements held with their individual customers, for example, where a customer would accept to activate demand-side ORC measures during supply stress periods and as a result accept to receive less material. There is some evidence to suggest that some demand-side measures have been taken in the period since mid-November 2017.

Whichever ORC mechanism is used, the key principles must include that the agreed ORC level must be kept constantly available and must be able to be immediately dispatched to the full extent that is covered. The provider of the ORC service must also be fully reimbursed for all the costs involved in providing the services, even if the services are not actually used. Any reserve capacity available in the market that is not contracted, or that cannot be immediately dispatched, or that is not fully paid for, is not “true” ORC.

The recent NEA report entitled “Results from the Third Self-Assessment of the Global ^{99}Mo/^{99m}Tc Supply Chain” – NEA/SEN/HLGMR(2017)5 identified that progress towards implementing ORC had improved since a similar analysis performed in 2014. However, the report also identified that a major irradiator still remained only in the low category of “Some progress made” and that two irradiators had still made “No progress” in implementing ORC at all. The fact that paid ORC has only been fully implemented for around 60% of the total theoretical supply capacity in the market is important. It identifies that while clear targets for the level of ORC are identified (e.g. the +35% ORC in this report), the market itself has probably not yet fully implemented these levels throughout the whole supply chain.

As paid ORC is probably not fully implemented in the present supply chain, some supply chain members are either choosing to ignore the need for contracted reserve capacity, or they are contracting it only at a level somewhat below the +35% guidance level. Any under-contracting of “true” ORC by the supply chain gives customers and stakeholders a false sense of security; supply chains with insufficient levels of paid ORC carry a higher risk of supply of disruption and increase the chance that potential reserve capacity available in the market may not actually be usable during a supply stress event.

Given that the actual ORC level required for each supply chain participant will change over time, the ORC level in this document should only be used with caution in providing advice or making decisions. The NEA believes that the demand curve with +35% ORC remains a good representation of a “safe” level of paid ORC capacity required to meet market demand under a (n-1) supply stress situation. However, this is dependent on the reserve capacity held by market players being “true” ORC that fully meets the key principles discussed in the section above.

Chapter 3. Scenarios and assumptions for ^{99}Mo/^{99m}Tc production capacity

The NEA regularly updates the list of current and planned new ^{99}Mo/^{99m}Tc irradiation and processing projects. The updates include: revisions to production start/end dates, review of the status of “qualified” potential projects and the anticipated impacts of some existing supply chain participants converting to using LEU targets. Appendix 1 provides tables that list current and some potential new ^{99}Mo/^{99m}Tc producers, along with the status of “qualified” projects as of April 2018. It should be noted that the tables are not exhaustive and do not include every potential project for ^{99}Mo/^{99m}Tc production that exists around the world. Inclusion in the tables does not indicate the NEA’s expectation that potential new production facilities may be operational by the indicated times, or even at all.

Supply chain participants acknowledge that, given the inability to store these radioisotopes for later use, the actual weekly ^{99}Mo/^{99m}Tc production levels will generally match the market demand. Therefore, the intent of this capacity projection is not to predict the actual level of ^{99}Mo/^{99m}Tc produced in a specific period. It is intended to identify periods of increased risk of supply shortages in order to inform government policy makers, industry and nuclear medicine professionals. Such higher-risk periods are when the projected production capacity curve is close to or below the projected NEA demand curve +35% ORC; that is the green line shown in the graphs in this report.

In this report, the time horizon for ^{99}Mo/^{99m}Tc production capacity is the six-year period 2018-2023, a period that includes important anticipated changes in global production capacity, following the period ending late March 2018 when the NRU reactor and Canadian Nuclear Laboratories (CNL) and Nordion processing capacity have no longer been held on “hot standby”.

The period anticipates the commissioning of new reactor- and non-reactor-based projects around the world. The capacity scenarios presented in this document are based on the data in Appendix 1, with some caveats[2]. Appendix 1 provides the current available maximum weekly capacity for producing reactors and processors under normal operating conditions. It should be noted that this maximum capacity level may not be available for every week of operation.

This report explains the results obtained from three capacity scenarios for the 2018-2023 period, presented in six-month intervals (January-June and July-December):

- Scenario A: “Reference” scenario – a baseline case that includes only currently operational irradiation and processing capacity.
- Scenario B: “Technological challenges” scenario – this adds to scenario A the anticipated projects, but, in most cases, not all of their planned new ^{99}Mo production capacity. Conventional reactor-based projects, given their proven technology and the direct access of product to the existing supply chain, are assumed to start production on their announced commissioning dates and are included in the analysis from their first full year of production. Alternative non-

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[2] See the notes appended to each table in Appendix 1.

conventional technology projects (including reactor- and non-reactor-based projects) are assumed to have a 50% probability of starting full scale production on their announced commissioning dates. So given the unproven nature of these alternative technologies and in some cases, their more difficult access routes to the market, only 50% of this new capacity is included in the projection from their anticipated first full year of operation.

- Scenario C: "Project delayed" scenario – this builds on scenario B by further assuming that LEU conversion activities and all new projects are delayed by one year further beyond their present anticipated first full year of production.

A so-called "all-in" scenario (where all the planned new/replacement projects are included at full projected capacity) is not reported. If all new potential projects proceed at the capacities and times as presently announced, there will be significant overcapacity of supply in the ^{99}Mo/^{99m}Tc market by 2023, a capacity level that is unlikely to be sustainable by the market in the long term.

In all three scenarios, the six-month projection intervals are based upon a weighted split of planned operating capacity between the two six-month periods, adjusted for the anticipated operational patterns provided by the existing operators where that is known.

It should be noted that the scenarios B and C in this report do not include all of the announced projects included in Appendix 1. In this report, a total of four projects have been excluded as their likely commissioning dates have been delayed beyond 2023. This is not to suggest that those projects will not become operational, but recognises that they are now not scheduled to become operational in the forecast period (2018-2023).

The approach for this report concerning the effects of LEU conversion is similar to that used in the April 2017 report and a simple blanket effect of a 10% level of efficiency loss has been applied in all cases where LEU conversion is still to take place. The timing of this effect is guided by the latest LEU conversion time plans provided to the NEA by the relevant supply chain members.

It should be noted that the ^{99}Mo processing facility operated by Curium in the Netherlands announced a 100% conversion to LEU targets in mid-January 2018 and that some, but not all reactors supplying irradiation capacity to that facility have adjusted their irradiation capacity to a lower level based upon their experience of irradiating LEU targets. This confirms the anticipated effect of some reduction in irradiation efficiency experienced with LEU targets. Curium did not adjust the level of anticipated processing capacity available as a result of 100% LEU target conversion. As more than 70% of the global market has now converted to LEU, the level of future impact of conversion to LEU on overall capacity levels has reduced compared to earlier reports.

Chapter 4. Reference scenario: A

The reference scenario includes only current approved ^{99}Mo production capacity, that is, the irradiators and processors that are part of the current global supply chain, including Argentina and Russia and also since early 2018, the first NorthStar project in the United States. It should be noted that capacity that was identified in previous reports as "transitional" (e.g. anticipated to be introduced by 2017) and that has now been successfully added to the global supply chain, is included in the reference scenario.

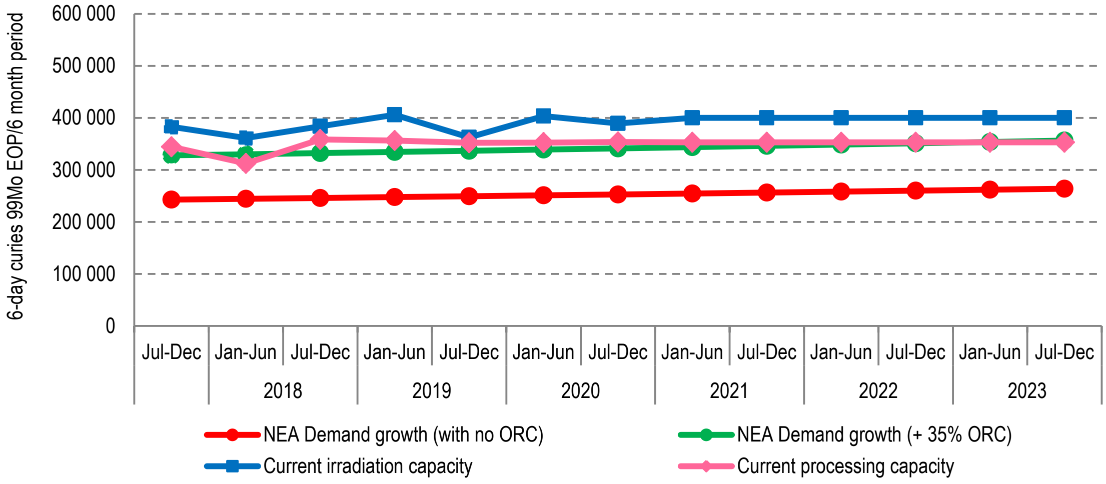
The supply chain successfully implemented additional capacity to progressively raise the level of the reference scenario in small steps in the 2016 and 2017 period. However, in this report, some irradiation capacity reductions have been reported, which are linked to the conversion to LEU targets used at the Curium processing facility. There has also been a reduction reported in the general capacity available in Russia.

It should be noted that the NRU reactor ended routine ^{99}Mo production in October 2016, which reduced the routinely available irradiation capacity and also took the associated processing capacity provided by CNL/Nordion offline. The NRU reactor ended all operations in late March 2018 and all potential contingency capacity from this source that was discussed in earlier reports has been removed from this report.

Reference scenario: A – Irradiation and processing capacity

Figure 4.1 shows the projected 2018-2023 global NEA demand estimate for ^{99}Mo, the NEA demand estimate +35% ORC, and the projected current irradiation capacity and current processing capacity based on reference scenario A. This is the capacity of the present fleet of irradiators and processors, inclusive of any planned additional capacity adjustments to those existing facilities. The NEA has added the preceding six-month period (July-December 2017) to all graphs to identify the capacity status in that period.

Figure 4.1: Demand (9 400 6-day Ci ^{99}Mo/week EOP) and demand +35% ORC vs. current irradiation and current processing capacity, 2018-2023: Scenario A



Reference scenario: A – Irradiation capacity

2018 began with the NTP (South Africa) facilities in an unplanned shutdown mode. The facilities only returned to service in late February and at a reduced capacity subject to regulatory oversight. As a result, a proportion of anticipated capacity from NTP has been lost in the first half of 2018. In Figure 4.1, the irradiation capacity for the July-December 2017 and January-June 2018 periods have been adjusted to reflect that unplanned loss. Curium announced the conversion to 100% use of LEU targets in mid-January 2018 and a reduction in overall operating capacity in Russia was reported.

In the reference scenario A, the global irradiation capacity decreases in the January-June 2018 period compared to late 2017 due to a combination of the unplanned NTP outage, the adjustment to operating capacity in Russia and reductions in capacity advised by some irradiators of LEU targets that supply the Curium processing facility. Irradiation capacity in the July-December 2018 period is projected to recover primarily due to the recovery of capacity in South Africa and the introduction of the NorthStar natural molybdenum activation product that allows the supply of the new RadioGenix Technetium generator system in the US market.

Irradiation capacity continues to recover in the January-June 2019 period due to improved reactor schedules; but then reduces in the July-December 2019 period, due to extensive planned irradiator maintenance periods at the BR-2 (Belgium) and LVR-15 reactors. Irradiation capacity is then projected to recover again in the January-June 2020 period and then stabilises for the rest of the period to 2023, remaining above the NEA demand + 35% ORC line. Overall, the irradiation capacity appears to be sufficient to assure supply throughout the projection period.

In Europe, a network of four reactors supplies two processing facilities, while ^{99}Mo-irradiating reactors outside of Europe each have associated processing facilities. The total European irradiating capacity under normal operating conditions has been greater than the total European processing capacity. The level of that additional irradiation capacity can be seen by comparing the irradiation and processing capacity curves in Figure 4.1. The additional irradiation capacity in Europe is projected to be low in the July-December 2019 period due to extensive planned maintenance at some reactors.

Reference scenario: A – Processing capacity

Figure 4.1 shows that the global processing capacity in the reference scenario A in the July-December 2017 period had increased prior to the unplanned NTP outage; this was due to the successful implementation of the transition project at ANM (Australia). The impact of the unplanned NTP outage combined with the reduction in operating capacity reported in Russia has substantially reduced total processing capacity to a level below the key NEA demand + 35% ORC line in the January-June 2018 period. During the first quarter of 2018 a chronic level of supply shortage has been experienced at the generator level of the supply chain, with some supply shortages in some markets throughout the period.

Total processing capacity is projected to recover in the July-December 2018 period based upon recovery of the NTP facility to full operating capacity and with the contribution of additional capacity from the NorthStar project. Processing capacity is then projected to remain relatively stable with only some minor LEU conversion effects and to remain a little above the key NEA demand +35% ORC line until crossing that line again in 2023. The level of projected global processing capacity from existing facilities is projected to be uncomfortably close to the NEA demand +35% ORC line throughout the period.

Overall, the current irradiators and processors, if well maintained, planned and scheduled, should be able to manage limited periods of unplanned outage of a reactor or a processor during the projection period. The capability to manage any longer-term adverse events, in particular for processing capacity, is very low and this capability reduces throughout the reference period.

In particular, the processing capacity from existing facilities has only very limited capacity above the NEA demand +35% ORC level for the final 4 years of the reference scenario and crosses below that key line in 2023. If no additional capacity is added above scenario A (that represents only existing suppliers), then the security of supply risks being compromised if unplanned outages occur, with the risk increasing in later years. Risk will also be increased when the full supply chain does not fully hold the recommended level of paid ORC.

Chapter 5. Technological challenges scenario: B

The technological challenges scenario in this report has carried over the principles from the previous reports. The scenario is a direct extension of the reference scenario A presented in the previous section, and includes the addition of "qualified" new reactor and alternative technology projects.

In the preparation of this report, the tables A1.1 to A1.4 shown in Appendix 1 were thoroughly reviewed and revised in consultation with supply chain participants using a standard format of project timeline reporting. It should be mentioned that not all new projects announced around the world have been included in this technological challenges scenario. Only projects that have been "qualified" are included, that is, those where adequate levels of data have been provided to the NEA and where the operational timeline is anticipated within the 2018-2023 projection period.

More specifically, the NEA has decided to only consider new projects that are likely to be commissioned and operational for at least one year before the end of 2023. Projects that are excluded are those that have unspecified construction start and commissioning dates, or for which there is inconclusive information about likely operational dates. By making such a determination, the NEA is not suggesting that any excluded projects will never materialise, but rather that they may not be commissioned within the forecast period. Projects are not included or excluded on the basis of their proposed technology.

Furthermore, all new alternative technology projects whether reactor-based or non-conventional reactor-based are assumed to have a 50% probability of being commissioned within their announced timelines. This assumption is to account for the fact that alternative and non-conventional technologies have yet to be proven on a large scale in the ^{99}Mo/^{99m}Tc market. This has been translated by applying only 50% of the expected maximum capacity to the forward projections for each of those projects.

Appendix 1 (Tables A1.3 and A1.4) continues to include some planned "qualified" projects that were in previous reports and were previously expected to be commissioned by 2023. The scenarios B and C (see also Chapter 6) include all but four of these projects. The four exclusions from the scenarios are:

- The proposed Korean reactor and processing facility; the project is in early construction phase, but was put on hold due to an earthquake and will be the subject of further seismic investigations before proceeding. The project construction permit is under review by the national regulatory body and the project will not start before 2023.
- The Polish processing facility associated with the MARIA reactor, which is still subject to budget approval and is now not scheduled to start before 2023.
- The Brazil MR reactor and processing facility project, which is now scheduled to have its first full year of operation later than 2023.
- The China Advanced Research Reactor and associated ^{99}Mo processing facility, where no firm project planning to achieve operation by 2023 could be ascertained.

The number of potential projects where the project timeline has moved the implementation date beyond 2023 (shown as 2023+ in the tables) is the same as in the 2017 report, indicating that all have suffered a further project delay of at least one year. These multi-year project delays and the reported delay in a number of the projects that still remain within the 2018 to 2023 projection period is a concern. A review of these projects over sequential NEA reports identifies many multi-year delays involving both conventional and alternative technologies. Multi-year delays often seem linked to budget problems, although some delays are also due to technical and licensing delays. It should be assumed that timeline slippage will continue to affect many projects that have yet to secure full funding and/or all relevant licence approvals.

In 2018, no new projects with the potential to become operational by 2023 have been added to this analysis. The remaining two projects that support increased supply capacity to the recently licenced NorthStar RadioGenix equipment remain in this section of the analysis. It should be noted that the successful licensing of the RadioGenix system can provide a potential route to market for other "non-uranium fission" based ^{99}Mo projects.

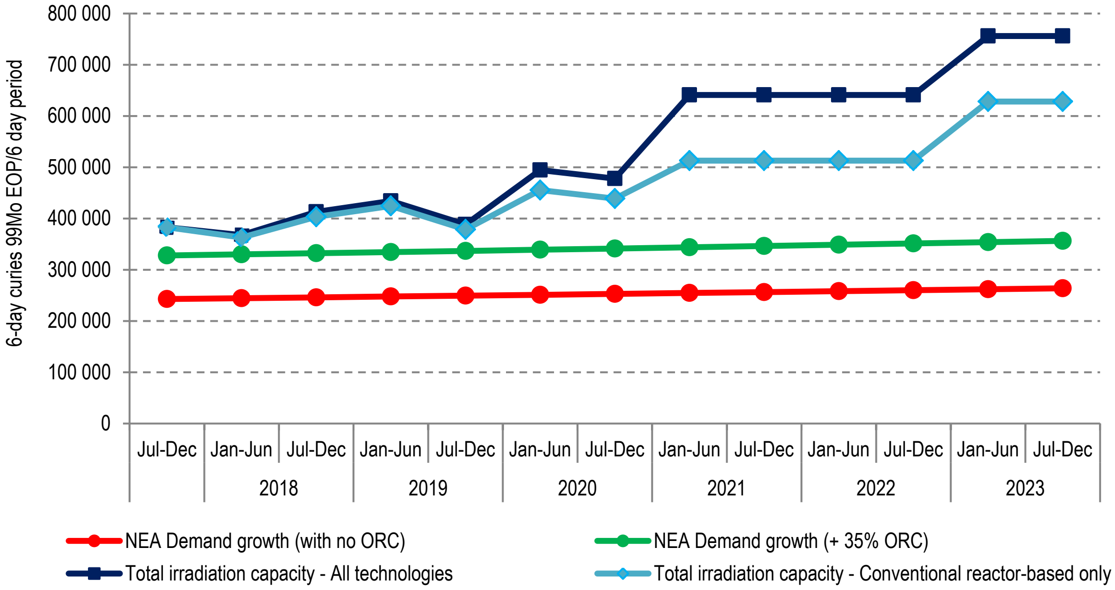
On 4 April 2018, Nordion announced that it would withdraw from a project in collaboration with General Atomics (GA) and the University of Missouri Research Reactor (MURR) to develop a new reactor-based source of ^{99}Mo. This project had been included in recent NEA reports; following the announcement, the project has been removed entirely from this report.

In the time frame beyond 2023, the proposed projects for ^{99}Mo/^{99m}Tc irradiation and associated processing capacity, if all completed, would significantly exceed the projected market demand. However, this apparent future excess capacity should not imply that long-term security of supply is assured. It does not take into account any current capacity being retired early, or the potential for continued multiple-year delays of projects, or consider any commercial sustainability effects that future potential supply "overcapacity" may have on the market.

Technological challenges scenario: B – Irradiation capacity

Figure 5.1 presents the NEA projected demand, projected demand +35% ORC and the irradiation capacity under the technological challenges scenario B. This shows both total capacity "all technologies" and capacity for "conventional reactor-based only". It can be seen that even without all planned new irradiation projects being fully included, the global capacity of both lines looks to be sufficient to meet projected demand +35% ORC throughout the six-year projection period.

Figure 5.1: Current demand (9 400 6-day Ci ^{99}Mo/week EOP) and demand +35% ORC vs. irradiation capacity – total and conventional reactor-based only, 2018-2023: Scenario B



To compare the effect that alternative ^{99}Mo/^{99m}Tc production technologies may have upon irradiation capacity, Figure 5.1 separates out conventional (reactor-based) irradiation capacity from total irradiation capacity. These lines now start to diverge in the January-June 2018 period when initial quantities of product from the NorthStar RadioGenix project start to enter the market.

Irradiation capacity dips in the January-June 2018 period due to the reductions in existing capacity described in scenario A, and is then projected to increase in the July-December 2018 period, supported by the completion of the ANM (Australia) project. As in the reference scenario A, the irradiation capacity continues to increase in the January-July 2019 period due to improved reactor scheduling and then reduces in the July-December 2019 period due to extensive planned maintenance periods at some reactors.

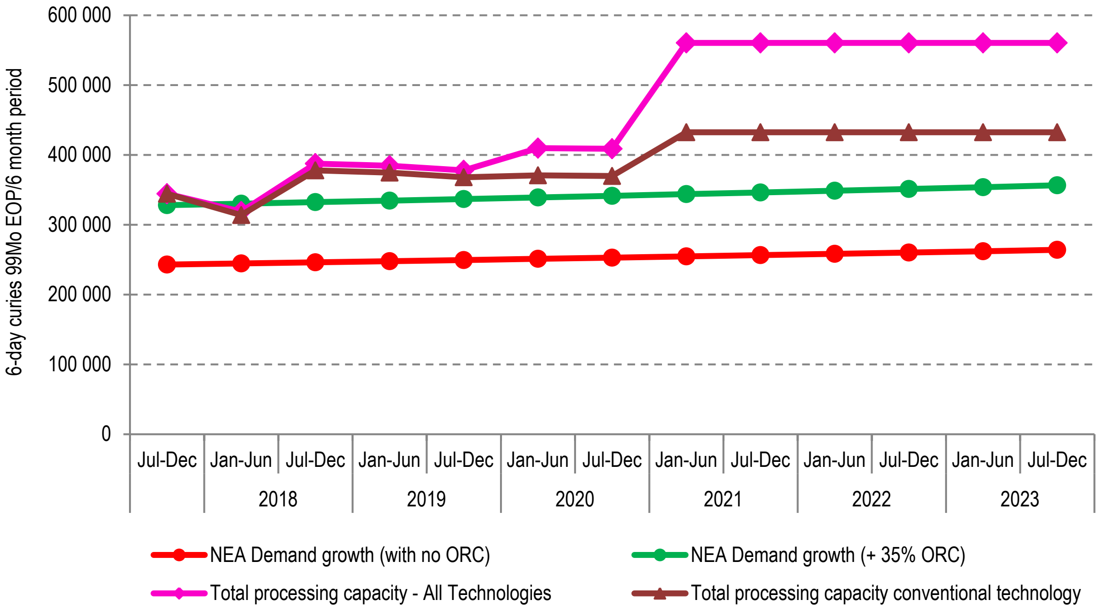
Substantial additional conventional irradiation capacity is projected to be added at the FRMII reactor (Germany) from 2020, the RA-10 reactor (Argentina) in 2021 and from the JHR reactor (France) in 2023. Additional irradiation capacity from “alternative technology” will only substantially add to security of supply from 2020, the additive capacity from “alternative technology” projects coming primarily from the United States.

The total irradiation capacity projected by 2023 is around 8% lower than the equivalent capacity projection to 2022 made in the 2017 report; this reduction in projected longer-term capacity is due to the withdrawal of the Nordion/GA/MURR project.

Technological challenges scenario: B – Processing capacity

Figure 5.2 presents the NEA projected demand, projected demand +35% ORC and the processing capacity under the technological challenges scenario B. This shows both total processing capacity “all technologies” and processing capacity for “conventional technology only”. It can be seen that even without all planned new processing projects being fully included, the global capacity of both lines looks to be sufficient to meet the projected demand +35% ORC requirement throughout the six-year projection period.

Figure 5.2: Current demand (9 400 6-day Ci ^{99}Mo/week EOP) and demand +35% ORC vs. processing capacity – total and processing capacity – conventional only, 2018-2023: Scenario B



As in scenario A, global processing capacity had increased in the July-December 2017 period with increased capacity available from the successful implementation of the transition project at ANM (Australia). The overall processing capacity from the January-June 2018 period is then projected to reduce to below the NEA demand +35% ORC line due to the NTP outage effects and the adjustments in operating capacity reported in Russia and described in the reference scenario. Processing capacity then increases in the July-December 2018 period with projected completion of the ANM project and is supported by a full half year of availability of capacity from the NorthStar project. Capacity then remains relatively stable during 2019 with only some minor LEU conversion effects.

Alternative processing technology capacity from the NorthStar project supports security of supply from 2018 onwards. Total processing capacity is projected to increase in 2020 with further contributions from alternative technology projects from NorthStar enriched Mo targets and in 2021 from SHINE (both United States). Processing capacity from conventional technology is projected to be added in 2021 (Argentina). From 2021 onwards, no further processing capacity is projected to be added in the period to the end of 2023.

The total processing capacity projected by 2023 is around 8% lower than the equivalent capacity projection to 2022 made in the 2017 report; this reduction in projected longer-term capacity is due to the withdrawal of the Nordion/GA/MURR project.

Some alternative technology processing capacity is linked one-to-one with alternative technology irradiation capacity; in those cases, both the irradiation and the processing components of those projects must be successfully deployed for those technologies to provide additional processing capacity to the supply chain.

Chapter 6. Project delays scenario: C

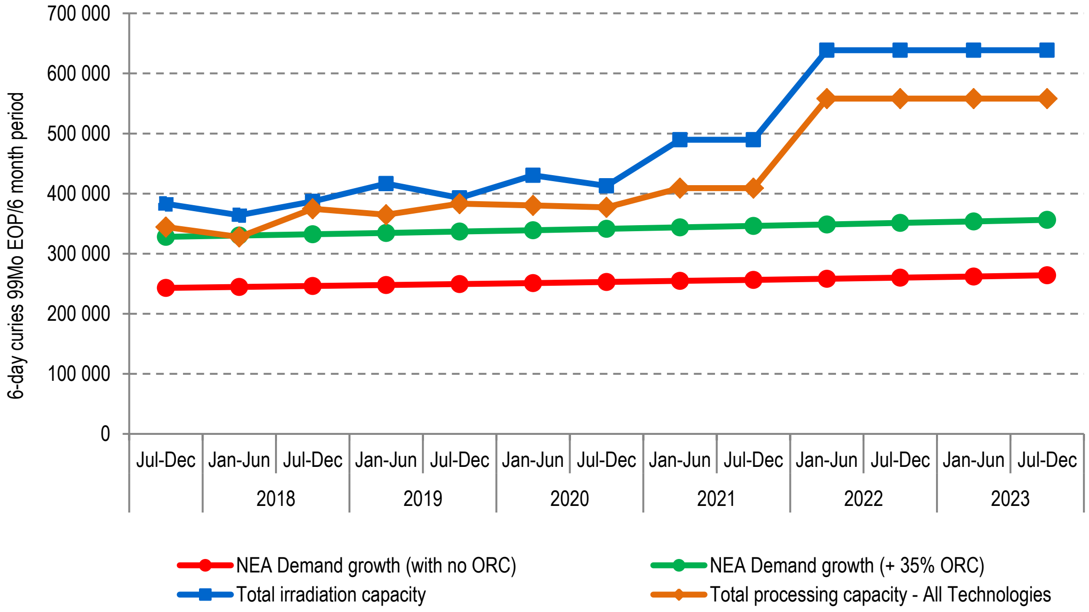
The project delays scenario C has been developed from the technological challenges scenario B by modelling a delay by one year for all new projects and remaining LEU conversion activities. This scenario considers the theoretical impact on future capacity when considering the technical complexity of new reactor-based projects and the often ground-breaking efforts in reaching large scale, commercial production by alternative technologies.

Experience has shown that large projects often take longer to complete than originally envisaged, with multi-year delays not uncommon. This has already been clearly demonstrated in previous NEA reports and in the analysis of scenario B in this report. As further project delays can be anticipated, the project delays scenario C is probably the scenario most likely to reflect future events.

Project delays scenario: C – Irradiation and processing capacity

Figure 6.1 shows the projected global irradiation and processing capacity under the project delays scenario C. Under this scenario, delayed new capacity will have a negative effect on both irradiation and processing capacity, but at the same time, delayed LEU conversion will have some opposite effect in the early years, provided that sufficient inventories of high-enriched uranium (HEU) for targets are available for the period of any delay.

Figure 6.1: Current demand (9 400 6-day Ci ^{99}Mo/week EOP) and demand +35% ORC vs. total irradiation capacity and total processing capacity – projects delayed, 2018 – 2023: Scenario C



After recovering from the low level of processing capacity in the January-June 2018 period that results from the unplanned NTP outage, the projected capacities for both irradiation capacity and processing remain above the NEA demand +35% ORC line throughout the reference period.

The total irradiation capacity for scenario C in 2018 is projected to be a little lower compared to scenario B due to the assumed delay in the final completion of the ANM project. In contrast, the total projected processing capacity for scenario C in the January-June 2018 period is slightly higher than in scenario B, with delays to LEU conversion effects offsetting the delay in the ANM project.

Both total irradiation capacity and total processing capacity remain relatively flat through 2019 and 2020 with irradiation capacity showing the same half year variability described earlier in the report due to reactor scheduling and planned maintenance periods. In 2021 and 2022, substantial increases in total irradiation and total processing capacity are projected, much of it from alternative technologies, but compared to scenario B, their introduction is delayed by 1 year.

As was the case in the 2017 report, the effects of project delays modelled in scenario C in this 2018 report are less pronounced than the anticipated effects that had been projected in the 2016 report. This is because a substantial amount of the additional irradiation and processing capacity that was previously projected from the transition project in Australia has now been locked into the reference scenario A. Only a smaller proportion of the total additional capacity from Australia will therefore be contributed by the completion of the ANM facility and affected in any "project delays" scenarios.

The total capacity levels that are now projected to be achieved by 2023 are lower than the equivalent capacity projections to 2022 made in the 2017 report. This is again due to the withdrawal of the Nordion/GA/MURR project.

The potential impact of project delays that are more extended is relevant; history confirms that most projects experience some delays and sometimes multi-year delays. Figure 6.2 looks at the potential impact of even longer delays and concentrates only on processing capacity, because it has lower levels of reserve capacity in all scenarios.

Figure 6.2: Current demand (9 400 6-day Ci 99Mo/week EOP) and demand +35% ORC vs. processing capacity – current, total, total conventional only and total two-year delay, 2018-2023: Scenarios A + B + C (two-year delay)

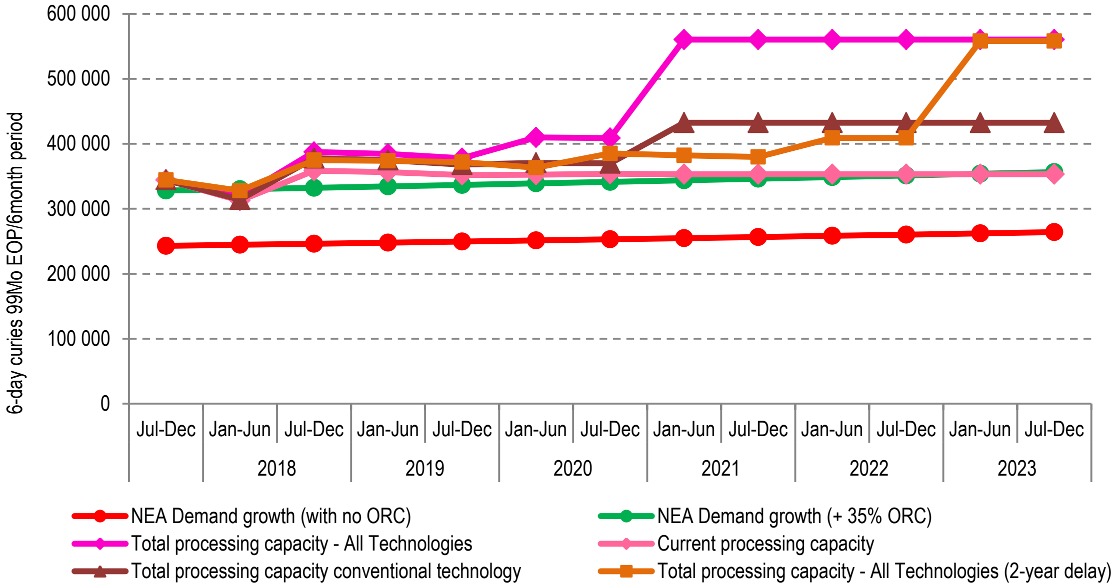


Figure 6.2 shows projected demand and projected demand +35% ORC lines compared to the current processing capacity (from scenario A), the projected total processing capacity and the projected capacity for conventional technologies only (both from scenario B) all with no project delay included. Figure 6.2 also projects a total processing capacity line with a two-year total project delay. The graph lines therefore represent the minimum, the maximum and two potential intermediate lines representing different challenges for processing capacity through the reference period.

The impact of assuming two years further delay in all processing projects has a similar pattern to assuming only adding processing capacity from conventional technologies during the period until 2021. When only conventional technologies are considered, the projection (from scenario B) only shows increased capacity from 2021 and the total processing capacity line with a two-year total project delay only shows limited capacity increases until 2022, with a substantial increase in capacity only projected in 2023.

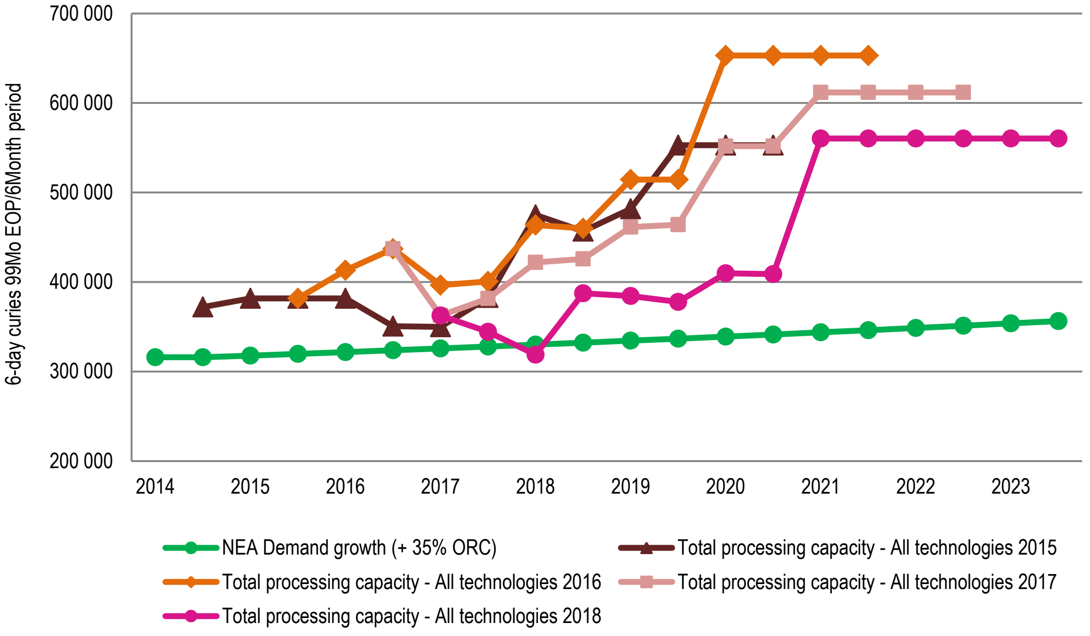
After recovering from the reduction in capacity from the NTP outage in the January-June 2018 period, in all cases other than the reference scenario A, the projected processing capacities do stay above the NEA demand +35% ORC line throughout the reference period. However, both of the intermediate projections confirm that a substantial reduction in overall projected processing capacity occurs when projects are severely delayed, or when only conventional technology is deployed as scheduled.

This reconfirms the importance of the successful introduction of some further capacity from alternative technologies to support security of supply in the medium term. Without successful deployment of some alternative technologies, the total processing capacity projected remains close to the NEA demand + 35% ORC line until 2021 and with that only being the case when the planned conventional technology project in Argentina remains on schedule.

Chapter 7. The cumulative effect of project delays

The report series since 2014 has identified multi-year delays can occur to potential new projects during their development. Figure 7.1 shows the cumulative effect of project delays by modelling the change to the "Technological challenges scenario B" projection line for total processing capacity on a year-to-year basis for the period starting in 2015.

Figure 7.1. Scenario B – "Technical Challenges": Effect of Multi-year Delays



In Figure 7.1, the projection for total processing capacity for scenario B in 2015 (dark brown line) anticipated a reduction of processing capacity by 2017 (e.g. the period after the end of NRU routine production), followed by a recovery in capacity by 2018, which then continued to mostly increase in a number of steps out to 2020.

By 2016, the equivalent scenario B projection (orange line) showed that substantial actions had been planned by the existing supply chain members, either through increasing capacity from existing facilities, or by adding additional capacity and making transition plans. These actions anticipated adding some capacity in 2016 ahead of the end of NRU routine production and still anticipated some reduction in capacity in 2017 when the NRU stopped routine production. The projection then stabilised in 2017 and projected increases from 2018 onwards, with the total anticipated capacity by the 2020 being higher as other new projects were added.

The 2017 projection of scenario B (pink line) showed that not all of the additional capacity anticipated in the 2016 report had been achieved and that the reduced capacity anticipated at the end of NRU routine production would be deeper than in the 2016 projection. The 2017 projection also anticipated some minor project delays in capacity introduction from 2018 onwards (the graph line moves to the right) and a decrease in the anticipated total capacity by 2021 as some new project capacity estimates were scaled back.

The latest 2018 scenario B projection (red line) shows the negative effect of the NTP unplanned outage on the short-term outlook in 2018 and also identifies more extended delays to the introduction of planned additional capacity. The 2018 projection also identifies a further decrease in the total anticipated capacity that would be achieved by 2021 as a result of the withdrawal of the Nordion/GA/MURR project.

When compared with the 2016 projection (orange line), the 2018 projection (red line) shows the main bulk of the potential projects that were anticipated have been progressively delayed to later years and sometimes by more than 1 year. The effect of the delays can be seen in the sequential scenario B projection lines that move in progressive steps both to lower levels and also to the right side of the graph. The total processing capacity in the 2019-2020 period in the 2018 scenario B projection is now anticipated to be the lowest level since the start of this series of projections.

The cumulative effect of unplanned outages, project delays and project cancellations suggests that total processing capacity will now remain under pressure until at least 2020. It should be noted that the projections shown in Figure 7.1 are from scenario B and are therefore relatively optimistic projections; Figure 6.2 shows more likely projections for the total processing capacity that will be available during the 2018 to 2020 period.

Chapter 8. Conclusions

The global estimate of demand growth has been maintained as in previous reports and used the same levels of annual increase since 2014; as a result, the projected demand level in 2018 has increased to approximately 9 400 6-day Ci ^{99}Mo per week EOP. The level of production required at end of processing (EOP) at the processor point in the supply chain has probably increased since the end of routine production in Canada due to the lengthening of some supply lines that has increased overall decay loss during transportation.

This increase in production requirement is unlikely to represent an actual increase in product demand at the final end-user level in the supply chain, so should be considered as an extra stress and an extra cost to the system.

There have been positive developments, with conversion to 100% production using low-enriched uranium (LEU) targets at the Curium processing facility in early January 2018 and the licensing of the first alternative technology, the NorthStar RadioGenix generator system in early February 2018. However, addition of further processing capacity from the new ANM facility has been delayed and some irradiation capacity reductions have resulted from LEU conversion that confirm decreased efficiency in LEU target irradiations.

The extended unplanned outage at the NTP facility has pushed processing capacity below the NEA demand +35% outage reserve capacity (ORC) guideline in the January-June 2018 period. Further delays have been experienced in the introduction of some alternative irradiation and processing technologies and the Nordion/GA/MURR project has been withdrawn. Delays to large conventional technology projects have continued and pushed back those projects beyond 2023. The multi-year delay of many projects remains a concern.

Potential contingency capacity from the NRU reactor and associated processing facilities are no longer considered in this report as NRU ceased all operations at the end of March 2018; the contingency capacity was not used during the period when it was available.

When facilities are well-maintained, well-scheduled and when unplanned outages are avoided, total irradiator and processor capacity should be sufficient. When the supply chain has fully implemented the recommended paid levels of ORC, the supply chain should be able to manage a limited unplanned outage of a reactor or a processor during the period to 2023. However, when no additional processing capacity is added above the present level, the capability to manage any adverse events, particularly concerning ORC will be low and will reduce progressively with time.

The supply situation will continue to require careful and well-considered planning to minimise security of supply risks and to react effectively in the event of unplanned outages. A high degree of co-operation between all supply chain participants will continue to be essential for the foreseeable future and the supply chain must diversify further and implement sufficient “true” paid ORC to ensure against the risks of supply disruptions. The market situation requires regular monitoring and review of the success in bringing proposed new production capacity to market.

References/further reading

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All of the above reports are available at www.oecd-nea.org/med-radio.

Appendix 1.

Table 1. Current irradiators including those in transition by 2023

Reactor (Fuel)	Current targets[7]	Normal operating days/year	Anticipated ^{99}Mo production weeks/year	Expected available capacity per week (6-day Ci ^{99}Mo)	Expected first full year of ^{99}Mo production[8]	Expected available capacity per year (6-day Ci ^{99}Mo) by 2023	Estimated end of operation
BR-2 (HEU)	HEU/LEU	147	21	6 500	NA	136 500	At least until 2026
HFR[1] (LEU)	HEU/LEU	275	39	6 200	NA	241 800	2026
LVR-15 (LEU)	HEU/LEU	210	30	3 000	NA	90 000	2028
MARIA (LEU)	LEU	200	36	2 200	NA	79 200	2030
OPAL (LEU)[2]	LEU	300	43	2 150	NA	92 450	2057
RA-3 (LEU)	LEU	230	46	400	NA	18 400	2027 or earlier based on RA 10 introduction
SAFARI-1 (LEU)	LEU	305	44	3 000	NA	130 700	2030
RIAR[3] (HEU)	HEU	350	50	540	NA	27 000	At least until 2025
KARPOV[3] (HEU)	HEU	336	48	350	NA	16 800	At least until 2025
MURR[4] (HEU)	Natural Mo in CRR	339	52	750	2019	39 000	2037
OPAL[5] (LEU)	LEU	300	43	+1 350	2019	58 050	2057
FRM-II[6] (HEU)	LEU	240	32	2 100	2020	67 200	2054

Notes: 1). HFR capacity increased from 5 400 to 6 200 per week from 2017, 2). OPAL extra irradiation capacity now operating at 12 plates, 3). RIAR and KARPOV material needs to comply with specific requirements to be available in some markets, the KARPOV facility will be relicensed in 2020 to continue its operation, RIAR weekly production varies depending on RBT-6/RBT-10 availability, 4). MURR irradiations will provide the material for the NorthStar system from 2Q 2018, 5). OPAL extra irradiation capacity at 12 plates in the new ANM ^{99}Mo facility starts in early 2018, first full year 2019, 6). FRM II market entry dependent upon conversion of processors to LEU targets, full capacity will be available from Q3 2019, 7). HEU >20% enriched uranium, LEU <20% enriched uranium, 8). NA = not applicable

Table 2. Current processors including those in transition by 2023 Revision

Processor	Targets[5]	Anticipated ^{99}Mo production weeks/year	Available capacity per week (6-d Ci ^{99}Mo)	Expected available capacity per year (6-d Ci ^{99}Mo) by 2023	Expected first full year of ^{99}Mo production[6]	Expected year of conversion to LEU targets	Estimated end of production
ANSTO Health	LEU	43	2 150	92 450	NA	LEU	2057
CNEA	LEU	46	400	18 400	NA	LEU	2027 or earlier based on RA 10 introduction
IRE	HEU	52	3 500	182 000	NA	2018/2019	At least until 2028
Curium[1]	LEU	52	5 000	260 000	NA	LEU	Not Known
NTP	LEU	44	3 000	130 700	NA	LEU	At least until 2030
RIAR[2]	HEU	50	540	27 000	NA	2018	At least until 2025
KARPOV Institute[2]	HEU	48	350	16 800	NA	2018	At least until 2025
MURR/NorthStar[3]	Natural Mo target	52	750	39 000	2019	NA	At least until 2037
ANSTO Nuclear Medicine (ANM)[4]	LEU	43	+1 350	58 050	2019	LEU	2057

Notes: 1).Curium converted to LEU early 2018, 2). RIAR and KARPOV material needs to comply with specific requirements to be available in some markets, the KARPOV facility will be relicensed in 2020 to continue its operation, 3). NorthStar RadioGenix system approved by the FDA 8 February 2018, production starts 2Q 2018, 4). ANM extra processing capacity is additional and will use OPAL additional irradiation capacity, 5). HEU >20% enriched uranium, LEU <20% enriched uranium, 6). NA = not applicable

Table 3. Potential irradiators entering in period 2018 to 2023

Irradiation source (Fuel)	Targets/technology[5]	Expected operating days/year	Anticipated Mo-99 production weeks/year	Expected available capacity per week (6-d Ci ^{99}Mo) by 2023[6]	Potential annual production (6-day Ci ^{99}Mo) by 2023[6]	Expected first full year of production	Project status (January 2018)
MURR/NorthStar[1] (HEU)	Enriched Mo in CRR	339	52	+2 250	+117 000	2020	In production scale up
NorthStar (non U)	Non-fissile from Electron Accelerators	352	52	3 000	156 000	2021	Accelerator vendor selected, initiating scale up
SHINE (LEU)	LEU solution with DTAs and SAAs	350	50	4 000	200 000	2021	Construction Permit Granted
RA-10 (LEU)	LEU in CRR	315	48	2 500	120 000	2021	Finish Building during 2018
Jules Horowitz Reactor[2] (LEU)	LEU in CRR	220	24	4 800	115 200	2023	Under construction
Korea (LEU)[3]	LEU in CRR	300	43	*400*	*17 200*	2023+	Construction permit in review by regulatory body
Brazil MR (LEU)	LEU in CRR	290	41	*1 000*	*41 400*	2023+	Detailed design started in 2017. Construction depends on budget
China Advanced RR[4] (LEU)	LEU in CRR	240	34	*1 000*	*34 000*	2023+	Existing reactor under modification

Notes: 1). MURR/NorthStar Enriched Mo capacity is additional to the Natural Mo capacity when introduced, 2). JHR reactor begins active commissioning in 2021, but ^{99}Mo capacity not expected to be available until 2022, 3). Korea capacity is planned to increase further in stages after 2023 4). CARR is already operational, but date of ^{99}Mo availability is unknown and is not before 2022, 5). Mo = inactive Molybdenum, either natural or enriched, CRR = Conventional Research Reactor, LINACs = multiple linear accelerators, LEU <20% enriched uranium, DTAs = multiple deuterium-tritium accelerators, SAAs = multiple subcritical aqueous assemblies, 6). Numbers in *italics* indicate availability after 2022

Table 4. Potential processors entering in period 2018 to 2023

Processor	Targets[5]	Anticipated Mo-99 production weeks/year	Expected available capacity per week (6-day Ci) by 2023[6]	Expected available capacity per year (6-day Ci ^{99}Mo) by 2023[6]	Estimated first full year of production	Project status (January 2018)
MURR/NorthStar[1]	Enriched Mo target	52	+2 250	+117 000	2020	In production scale up
NorthStar	Non-fissile	52	3 000	156 000	2020	Accelerator vendor selected, initiating scale up
SHINE	LEU solution	50	4 000	200 000	2021	Construction Permit Granted
CNEA	LEU	48	2 500	120 000	2021	Building start by end 2018
Korea[2]	LEU	43	*400*	*17 200*	2023+	Construction permit in review by regulatory body
MARIA: Mo-99 2010[3]	LEU	40	*300*	*12 000*	2023+	Financing – not yet agreed
Brazil MR	LEU	41	*1 000*	*41 400*	2023+	Detailed design still to be contracted. Construction depends on budget
China Advanced RR[4]	LEU	34	*1 000*	*34 000*	2023+	Financing decision after 2017 tests

Notes: 1). MURR/NorthStar Enriched Mo capacity is additional to the Natural Mo capacity when introduced, 2). Korea capacity is planned to increase further in stages after 2023, 3). MARIA uses existing capacity at the MARIA reactor, 4). CARR is already operational, but date of ^{99}Mo processing capacity availability is unknown and not before 2022, 5). Mo = inactive Molybdenum, either natural or enriched, LEU <20% enriched uranium, 6). Numbers in *italics* indicate availability after 2022.