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The Supply of Medical Radioisotopes

An Economic Study of the Molybdenum-99 Supply Chain: Summary

NEA No. 6969

NUCLEAR ENERGY AGENCY
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FOREWORD

At the request of its member countries, the OECD Nuclear Energy Agency (NEA) has become involved in global efforts to ensure a reliable supply of molybdenum-99 (^{99}Mo) and its decay product, technetium-99m (^{99m}Tc), the most widely used medical radioisotope. The NEA Steering Committee for Nuclear Energy established the High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) in April 2009. The main objective of the HLG-MR is to strengthen the reliability of ^{99}Mo and ^{99m}Tc supply in the short, medium and long term. In order to reach this objective, the group has been reviewing the ^{99}Mo supply chain, working to identify the key areas of vulnerability, the issues that need to be addressed and the mechanisms that could be used to help resolve them.

Recognising that there could be a market failure in the ^{99}Mo supply chain, the HLG-MR asked the NEA Secretariat to undertake an economic study of the full supply chain. The goal of the study was to analyse the economics of the supply chain from the reactors to the end users (the patients), to develop a solid factual base of the supply chain and the various costs, to assess whether the market is failing and to suggest options to encourage sufficient investment in ^{99}Mo production capacity to ensure a long-term, reliable supply of ^{99}Mo and ^{99m}Tc.

The full report provides comprehensive information on the supply chain and possible changes needed. The historical development of the market has an impact on the present economic situation, which is currently unsustainable. The supply chain's economic structure therefore needs to be changed to attract additional investment in production capacity as well as the necessary reserve capacity. The report presents options that could be considered in that regard.

The report was prepared by the NEA Secretariat at the request of the HLG-MR. It does not necessarily represent a consensus view of the HLG-MR but is presented to enable discussions and further analysis among the members of the HLG-MR, other stakeholders and decision-makers. The individuals and organisations that contributed to the study are not responsible for the opinions or judgements it contains.

Acknowledgements

This report would not have been possible without input from a significant number of supply chain participants and stakeholders including all major reactor operators, all major processors, generator manufacturers, representatives from radiopharmacies and nuclear medicine practitioners (identified in Annex 1 of the full report). The input from the supply chain participants was essential for completing this study, and the NEA greatly appreciates the information provided by interviewees.

Drafts of the report were reviewed by members of the HLG-MR and supply chain participants who provided initial input. In addition, valuable comments were received during the presentation of the findings at the Third Meeting of the HLG-MR.

The report was written by Chad Westmacott of the NEA Nuclear Development Division. Detailed review and comments were provided by Ron Cameron, with other reviews and input from Jan Horst Keppler and Alexey Lokhov of the NEA Nuclear Development Division.

SUMMARY

Introduction

The NEA Steering Committee established the High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) in April 2009 to examine the problems and suggest possible solutions for ensuring a long-term reliable supply of molybdenum-99 (^{99}Mo) and technetium-99m (^{99m}Tc).

During early discussions, the HLG-MR discussed the possibility of there being a market failure in the ^{99}Mo supply chain, given that it was (and is) not economically viable for current reactor operators to produce irradiated targets containing ^{99}Mo, and that there are not sufficient financial incentives based on the current economic structure to develop additional infrastructure to produce ^{99}Mo. This means that recent ^{99}Mo supply shortages were a symptom of the longer-term problem related to insufficient capital investment for a reliable supply. In order to determine if there is a market failure in the supply chain, the HLG-MR requested that the NEA Secretariat undertake an economic study on the ^{99}Mo supply chain.

The study is based on input from supply chain participants, including all major reactor operators, all major processors, generator manufacturers, representatives from radiopharmacies and nuclear medicine practitioners. It examines the current situation, identifies the economic problems and suggests options to address those problems. The report is not intended to recommend a single solution but to present the full analysis of options. This recognises that economic considerations are only one factor that will affect the final decisions being taken about the future of this supply chain; policy, medical and technological factors are also important for decision makers to consider.

In order to be able to describe the current economic structure, and to do so in terms of the commonly used unit of curies, six days after the end of the processing stage of the supply chain (EOP), detailed analysis was performed on the costs and prices at all stages of the process, based on information provided by supply chain participants and using a range of assumptions. It is recognised that these calculations are only as good as the data from which they were derived but various checks were undertaken to verify that the results reflected the realities of the market, as determined from the interviews with participants. The data is presented as averages of the input provided to protect confidentiality. The reader should not see the averaged data as representative of any one individual supplier or region.

Sensitivity analysis shows that the uncertainties and variability in the data do not affect the final results relating to the overall magnitude of the changes required. Importantly, the final conclusions of the study are robust.

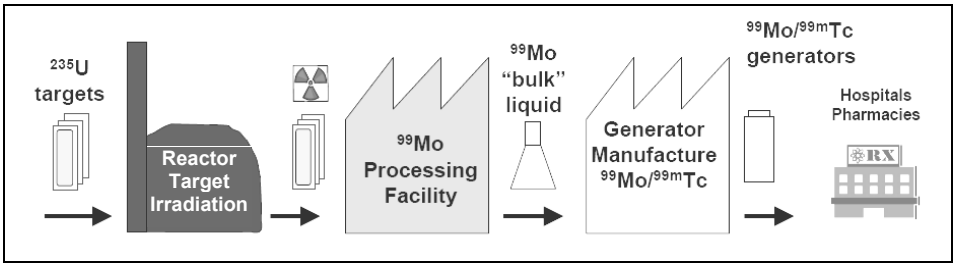
While the report focuses on existing production technologies, which mainly use highly enriched uranium (HEU) targets, the NEA notes the agreement among governments to move toward using low enriched uranium (LEU) targets for medical isotope production. The economic conclusions drawn in the report apply equally to ^{99}Mo production using LEU targets, either from conversion or from the development of new LEU-based production capacity.

Description of the supply chain and its historical development

Given the short half-lives of ^{99}Mo (66 hours) and ^{99m}Tc (6 hours), the logistical arrangements in the supply chain have to move very quickly and predictably to get the product delivered to the end user in its usable form – a prepared dose containing ^{99m}Tc for injection into the patient. ^{99}Mo cannot be efficiently stored over extended periods. For practical purposes, the economics and medical utility of ^{99}Mo/^{99m}Tc are dependent on minimising decay losses. Logistical efficiency and just in time delivery are essential to the realisation of the economic sustainability of the global supply chain.

The supply chain consists of target manufacturers, reactor operators who irradiate the targets to create ^{99}Mo, processors who extract the ^{99}Mo from the irradiated targets and produce bulk ^{99}Mo, generator manufacturers who produce generators with the bulk ^{99}Mo, and radiopharmacies and hospital radiopharmacy departments who elute ^{99m}Tc from the generator and couple it with "cold kits" to prepare radiopharmaceutical doses for nuclear medical imaging of patients (Figure E.1).

Figure E.1: ^{99}Mo supply chain



Source: Ponsard, 2010.

Historically, there were only five reactors that produced 90 to 95% of global ^{99}Mo supply, all of which are over 43 years old. In the past, other reactors produced ^{99}Mo but they have been shut down. The way that these reactors operate contractually with the processors is quite varied. There are three different market structures that have emerged based on the degree of responsibilities of the reactor and the vertical integration between the processor and reactor (described in the full report). Each of these structures can provide different challenges related to the economics, including the ability to have flexible pricing for services rendered as circumstances change.

All of the major producers of ^{99}Mo use multipurpose research reactors for target irradiation, which were originally constructed and operated with 100% government funding for research and materials testing purposes. When ^{99}Mo production started, the reactors' original capital costs had been paid or fully justified for other purposes. It was reported by interviewees that the production was seen as a by-product that helped provide another mission for the reactor and that could bring in extra revenue to the reactor to support its research. As a result, reactor operators reportedly originally only required reimbursement of *direct* short-run marginal costs; there was no consideration that ^{99}Mo should cover a share of marginal costs related to the overall reactor operations and maintenance. Further, there was no share of any capital costs included in the price of the ^{99}Mo, nor was there any allowance for replacement or refurbishment costs of the reactor facility.

The importance of ^{99}Mo production in these reactors increased over the years to the point where most of the major reactor operators indicated that it is now a significant factor behind reactor operating decisions. Even with this increased importance, the by-product status remained and there were no substantive changes to the pricing structure to reflect the larger share of the general operating and maintenance costs of the reactor that should be borne by ^{99}Mo production.

This market structure for the reactor stage of the supply chain poses some challenges for the reliable production of ^{99}Mo:

- The current fleet of ageing reactors is subject to longer and more frequent planned and unplanned shutdowns.
- The proposed conversions from targets normally containing between 45 and 98% ^{235}U (HEU) to targets containing less than 20% ^{235}U (LEU) may have impacts on reactor and processor economics based on additional conversion and operating costs.
- The current economic structure does not support the investments required for new production infrastructure, regional balance and the reserve capacity necessary for a reliable supply chain.

The processing component (i.e. extraction and purification of ^{99}Mo) of the supply chain was originally funded by governments as part of their efforts to develop the use of nuclear radioisotopes for medicine, recognising the significant health benefits of nuclear imaging techniques. In the 1980s and 1990s these components were separated from the reactors and commercialised. Although the commercialisation process was originally thought to be beneficial to all parties, reactor operators did not receive the benefits expected. Interviewees indicated that governments created the commercial contracts based on historical perceptions of costs and pricing structures and their interest in developing the nuclear medicine sector. This resulted in long-term contracts with favourable terms for the commercial processing firm; the separation of activities did not lead to a change to the commercial prices for the irradiation part of the supply chain. Once these contracts were established, they set the standard for new processors and reactors that entered the market.

In addition, the historical processing market was reported as being characterised by significant barriers to entry. Along with natural barriers to entry (being a knowledge and capital intensive industry), there were actions undertaken by existing firms that interviews indicated created barriers to entry. These actions, such as aggressive pricing strategies and exclusivity contracts, had the effect in many cases of convincing new entrants that they would not be able to compete profitably and thus they did not enter the market.

During the most recent supply shortage situation, much attention has been focussed on reactor capacity and reliability, but there are also limitations on processing capacity. These limitations predominately relate to the geographical location of processing facilities and the need for them to have reserve capacity.

Waste management is another important issue for the processing stage. A general economic model that incorporates the final treatment and disposal costs of the liquid radioactive waste is not available. It is generally accepted that the full final waste disposal costs are not included in the pricing. The conversion to LEU may increase this concern as more targets may need to be processed to obtain the ^{99}Mo, resulting in increased waste volumes and related in costs.

Generator manufacturers and radiopharmacies or hospital radiopharmacy departments represent the further downstream components. The principal challenge for the downstream actors is related to changes in reimbursement rates for SPECT[1] procedures, which could potentially affect the funds available to pay for the medical isotopes.

Overall, the ^{99}Mo/^{99m}Tc supply chain is very complex and faces a number of significant challenges, both short and long term. An ever-present factor in the supply chain is the need to get the product to the patient while minimising the decay of the product and related losses of its economic value.

Impacts of historical market development on current economic sustainability

The historical foundations have had, and continue to have, a significant impact on the current market structure, its economics and the ability to adjust the market to ensure economic sustainability.

Reactor irradiation prices set too low to support infrastructure development

As a result of ^{99}Mo production being seen as a by-product and reactor capital costs that were already paid off or fully justified, historical pricing of reactor irradiation services reportedly included very limited direct marginal costs and did not included replacement costs and full direct and indirect marginal costs. The non-inclusion of these costs has resulted in prices for target irradiation that are too low to sustainably support the portion of reactor operations that could be attributed to ^{99}Mo production and do not provide enough financial incentive to cover the attributable portion of costs for replacing or refurbishing ageing reactors. In some cases, the pricing does not even cover short-run marginal costs.

1. SPECT stands for single photon emission computed topography – the nuclear imaging technique which uses gamma rays produced by ^{99m}Tc.

Commercialisation reinforced low prices and created market power

The current supply chain economics was pivotally impacted by the commercialisation of the major processors in the supply chain. Apart from contracts not providing for the economic sustainability of ^{99}Mo irradiation services, they also resulted in some perverse economic effects, including encouraging some cases of potentially inefficient production of ^{99}Mo. For example, interviewees indicated that some contracts allowed for the processor to stockpile the rapidly decaying ^{99}Mo in order to smooth out customer supply. This type of behaviour greatly affected the economic return to the reactor and resulted in overproduction and an increase in related radioactive waste volumes.

Another effect of the commercialisation process was the establishment of a situation of market power for processors. The contracts, in some cases, provided for an exclusive relationship between the reactor and the processor, creating a situation of monopsony/oligopsony [a market dominated by one/few buyer(s)] whereby the reactor had only one avenue for selling its ^{99}Mo related irradiation services. This market power has contributed to maintaining low prices for irradiation services.

A further complicating factor was the historical existence of excess capacity of irradiation services. While some excess capacity is necessary for reliable supply, it is difficult to determine the difference between reserve capacity and overcapacity when services are not properly valued. This overcapacity coupled with an incomplete accounting for costs on the part of suppliers meant that the reactors would supply irradiation services even if prices were low. It was reported that purchasers could thus pay low prices for the irradiation services and look elsewhere for irradiation suppliers if prices were to increase.

The market power that existed and the related barriers to entry resulted in lower prices at the bulk ^{99}Mo stage than were necessary to encourage new entrants and created a situation of limiting the number of buyers of irradiation services. This maintained the buyer market power and perpetuated the pricing structure that was insufficient to cover full operational and replacement costs of reactors.

Downstream pricing perpetuated low prices

Interviewees indicated that generator manufacturers used low-margin selling models for ^{99}Mo generators, pricing them low to encourage sales of their cold kits. In addition, patent protection that allowed generator manufacturers to

obtain a return for the upfront research and development costs also allowed them to obtain economic returns for the combined product of the ^{99}Mo and the cold kits. This pricing model resulted in the companies making profits on the cold kits and not on the generators.

This undervaluation of the ^{99}Mo in the generator pricing had a feedback effect on upstream prices. Since the generator manufacturers captured the economic value of the ^{99}Mo through their sales of cold kits, the profits they made did not flow back up through the ^{99}Mo supply chain and limited the flexibility to absorb upstream price increases within *generator* prices.

These low prices for ^{99}Mo led to unsustainably low prices for the ^{99m}Tc, which were one factor, among many, that contributed to reimbursement rates for SPECT imaging procedures being set low. This has had a feedback effect on maintaining low prices in the upstream supply chain; as these reimbursement rates fell, some hospitals reportedly have negotiated even lower rates for the ^{99m}Tc.

Government support sustained the industry

The question that obviously arises at this point is: *If the supply chain pricing structure was such that the irradiation services were unable to be offered on an economically sustainable basis, why did reactors continue to irradiate targets?*

The answer to this question is related to the social contract that governments had established with the medical imaging community (whether implicitly or explicitly). Governments would subsidise the development of research reactors and related infrastructure and the operation of that infrastructure, including radioactive waste management. Using part of this funding, reactor operators irradiated targets to produce ^{99}Mo. In return for this use of taxpayer funds, citizens would receive an important medical isotope for nuclear medicine diagnostic procedures.

Although reactor operators were aware the government financial support was increasingly used for ^{99}Mo production, this change may not have been transparent to governments. In some cases, the magnitude of the change did not become evident until there were requests to refurbish a reactor or construct a new reactor. These subsidies were also supporting the production of ^{99}Mo that was exported to other countries. Recently, some governments have started to question their social contract with the medical community and with the reactor operators.

Result: Historical foundations created an economically unsustainable industry

The overall impact of the historical market development on the current situation is that there is currently not enough reliable reactor capacity and there are constraints on processing capacity. As explained above, this has been caused by a market structure that developed around an unsustainable economic model that did not remunerate reactor operators and processors sufficiently well to provide incentives to invest in new infrastructure to meet growing demand or to maintain reserve capacity.

This lack of investment has resulted in a system reliant on older reactors that have had reliability concerns over the last decade. The shortage seen in 2009 and 2010 is a **symptom** of this economic problem. Once the shutdown reactors return to operation and the short-term supply becomes stable again, it is important to stress that although the symptom has been addressed, the underlying problem – the unsustainable economic structure – has not.

Analysis of current economic situation

Calculations confirm that the industry is unsustainable

Based on information received during interviews with market participants at all stages of the supply chain, the cost and pricing structure of the ^{99}Mo supply chain were analysed to confirm the assessment that historical market development has resulted in an economically unsustainable supply chain.

Using the models developed and described in the report, the calculated prices of a six-day curie EOP are presented in the Table E.1. These prices are indicative of those seen before the supply shortage period of 2009-2010. During the shortage period, many market participants observed price increases, in some cases quite significant (upwards of 200% increases). These prices are not presented in this report as their longevity is not guaranteed and could be misleading as to the long-term economic sustainability of the supply chain.

From the values calculated using the model of the current economic situation, and the information provided on costs at the reactor stage, the analysis finds that the marginal revenue from production was lower than the marginal costs, with reactors facing a loss on average of EUR 26 on each ^{99}Mo six-day curie EOP produced (USD 36).

Table E.1: Selling price of six-day curie EOP pre-shortage*

	Selling price EUR/six-day curie EOP	Selling price USD/six-day curie EOP**
Reactor	45	60
Processor	315	445
Generator	375	520
Radiopharmacy	1 810	2 525

* As with all values presented in this report, these values are meant to be illustrative of the situation being described and should not be construed as being the absolute true value seen in the market.

** An exchange rate of EUR 1 = USD 1.395, which is the average exchange rate for 2009 taken from www.ecb.int (European Central Bank). Exchange rates for other currencies are discussed in Annex 2 of the full report.

To better understand the significance of the pre-shortage prices, it is necessary to look at the net value of each stage of the supply chain as a proportion of the final ^{99m}Tc dose price provided to the hospital for the patient procedure. Based on a median value of about EUR 11 (USD 15) for the ^{99m}Tc dose, the calculated net price of a six-day curie EOP at each supply stage is presented in the Table E.2.

Table E.2: Net revenue of each stage based on selling prices at the hospital stage – pre-shortage*

	Revenue of ^{99}Mo/^{99m}Tc within the radiopharmaceutical price		Share of revenue of ^{99}Mo/^{99m}Tc of each supply stage within the final reimbursement rate**
	EUR/dose	USD/dose	Per cent
Reactor	0.26	0.37	0.11
Processor	1.64	2.29	0.67
Generator	0.34	0.47	0.14
Radiopharmacy	8.62	12.02	3.51

* As with all values presented in this report, these values are meant to be illustrative of the situation being described and should not be construed as being the absolute true value.

** The total does not equal 100% as the reimbursement rate also pays the hospital for its facilities, the doctors and nuclear clinicians, etc. used during the nuclear medicine diagnostic procedures.

More important is the proportion of these prices within the final reimbursement rates[2]. Based on a representative reimbursement rate for a SPECT imaging procedure (calculated to be about EUR 245/USD 340 using a weighted median of reported values) the net share of that reimbursement rate that goes to each stage of the supply chain is also presented in the table above. As shown, the irradiation price from the reactor is less than one-fifth of one percent of the total reimbursement rate (calculated as 0.11%).

This low value for irradiation should not be interpreted as implying that significant profits are being made at any of the downstream stages or by the hospital itself. There is no reason in principle that the reactor should get any more than 0.11% of the final reimbursement rate, provided that production was economically sustainable, but this is not the case. The price increases at each subsequent stage are expected given other input costs at that level, such as labour and capital investments, as well as value added in terms of making the ^{99}Mo usable for the patient procedure and delivering the product to the next supply stage.

The values demonstrate that the economic structure is inadequate

The values presented in the report clearly show that there is neither sufficient financial incentive for the development of new capital infrastructure nor even for the maintenance of capital to ensure continued operation. The current pricing does not reportedly include any significant value for general overhead or full operating costs, or for capital maintenance or replacement of reactors. As a result, the costs presented here are less than what is required to be economically sustainable. The inclusion of these costs in the calculations would have increased the calculated losses in the current pricing structure for reactor operators.

In addition, the current economic structure does not provide any financial recognition of reserve capacity. Reserve capacity is back-up capacity to be used in two cases: 1) to account for operational down times of research reactors as they do not operate 100% of the time – weekly reserve capacity (WRC); and 2) in the event of unscheduled or extended maintenance outages – outage reserve capacity (ORC). Traditionally this meant that when one reactor was not operating, another could fill the void and irradiate targets for ^{99}Mo production.

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2. Reimbursement rates are the amounts paid to hospitals or clinics via public or private health insurance for the medical procedure undertaken and include the cost of the medical radioisotope.

Historically, WRC was the principal reason for reserve capacity development as the reactors were generally reliable. However, as the reactors (and processing facilities) have aged, there has been an increase in the incidences of unexpected or extended repair shutdowns and the ORC has become of paramount importance in the short term.

Overall, the effect of these poor economic conditions is that the ^{99}Mo supply chain currently relies on older reactors, new reactors are struggling to cover ^{99}Mo production investments, and there is not sufficient reserve capacity to ensure a reliable supply of ^{99}Mo. However, the demonstrated small share of the irradiation prices within the final reimbursement rate provides some hope for reaching a better economic structure, as any changes to upstream prices would be expected to have only small impacts on the end user.

Other issues increase the pressure on the unsustainable economic situation

There are a number of other issues within the industry that increase the impact of the current uneconomical supply chain. Industry stakeholders are being faced with possible additional economic pressures as a result of the conversion to LEU targets[3] and changing levels of government financial support for overall and reserve capacity. In addition, the pricing structure has resulted in examples of suboptimal use of ^{99m}Tc; however, this provides opportunities for demand management actions.

LEU conversion is necessary, but currently not supported by the market

Conversion to LEU targets for the production of ^{99}Mo has been agreed by most governments for security and non-proliferation reasons. In fact one major producer (NTP Radioisotopes) expects to have converted their reactor and processing facilities to use LEU targets in 2010. However, at this time there is not yet an established body of knowledge as to the comparative yield, waste management costs, development costs, capital requirements and the related economic impacts that would be observed for a major ^{99}Mo producer wishing to undertake conversion.

The main technical issue is the obvious fact that LEU targets contain less ^{235}U compared to the HEU targets currently being used. Since ^{99}Mo is a fission product of the ^{235}U in the targets irradiated in the reactor, there is an impact on the yield of product from a target with less ^{235}U. Two ways to compensate for

3. As discussed more fully in the report, some reactors have already made this change.

this are to increase the density of total uranium in the targets and to increase the number of targets irradiated. The former action is a source of much current research, as is the development of new technologies and targets to increase yields. The latter may affect other missions within the research reactor or may require more irradiation positions within the reactor.

Without these changes, an increase in costs per curie produced will occur, as there will be a need for some degree of additional irradiation and processing capacity to continue to produce the same quantity of ^{99}Mo globally, depending on the uranium density that can be achieved in the target. There may also be an increase in waste management costs (capital and operational) since more total uranium waste and liquid wastes will need to be managed. However, until final disposal strategies are implemented, it is difficult to quantify the cost increases. Reduced physical protection costs as a result of dealing with LEU instead of HEU may help to offset any potential cost increases of using LEU targets.

However, even with the uncertainty on the costs of conversion, the conclusion that the current pricing provides insufficient financial incentives is expected to be equally applicable to LEU, as the costs of ^{99}Mo production are generally expected to increase as the industry moves forward with LEU conversion, although the magnitude of any increase will depend upon the specifics of a particular situation.

Governments are re-examining their level of subsidies to reactors

There are indications that the traditional social contract that supported ^{99}Mo production has started to change. Governments from all of the current major global producers' countries have indicated that they are no longer interested in subsidising the ongoing production of ^{99}Mo at the reactor level at historical levels (or at all), some more formally than others.

This changing social contract is also relevant when looking at the possible development of new multipurpose research reactor projects that are being discussed to replace ageing reactors, as well as efforts to encourage the development of other production options. In most of these projects there has been an indication that ^{99}Mo production will have to be undertaken on an economically sustainable basis, including accounting for an attributable portion of the capital investment.

This change in the social contract has come about due to governments questioning whether it is still in the public interest, based on a number of reasons:

- Increased awareness by governments of the amount that they were subsidising ^{99}Mo production and the related waste management (with all its responsibilities).

- The growing proportion of reactor use for ^{99}Mo production brings with it questions of the government's role in a commercial activity, not only from a philosophical perspective but also a regulatory one.

- The taxpayer-funded subsidisation was mostly supporting the health care system of other countries, since much of the product was exported.

- The taxpayer may not benefit from the subsidisation when the irradiated targets or bulk ^{99}Mo are exported and the generators are then imported back into the country.

The historical social contract model also meant that reserve capacity was traditionally provided by governments – they paid for the capital costs for the capacity to exist and production was only done when required. Governments questioning whether to continue subsidising ^{99}Mo production would also impact their level of financial support for reserve capacity.

Any change in the social contract, with a move away from the traditional government role in subsidising the upstream industry, will have a significant impact on supply chain economics. With a changed social contract, the economics have to become sustainable on a full-cost basis or the availability of a long-term reliable supply of ^{99}Mo will be threatened.

Historical suboptimal use of ^{99m}Tc means there are demand management options

As with all products, when the price of ^{99m}Tc is low, people tend to use more or use it less efficiently. In some cases, this "use" meant letting the product decay without being used for a patient procedure, just to ensure its availability. During the current supply shortage, there have been many examples of better use of the ^{99m}Tc that confirm previous inefficient use. In many cases the reduced supply is not affecting the number of patients being tested or the quality of those tests.

Historically, there have been some preparation and delivery practices at radiopharmacies/hospital departments that may have been suboptimal, such as elution patterns that did not maximise the use of the ^{99m}Tc produced within the generator. Radiopharmacies, hospitals and physicians have been changing these

historic practices during the current shortage period to deal with a reduced supply. As well, there are a number of recent studies on SPECT procedures and advances in software that indicate the possibility of reducing the required dose of ^{99m}Tc for current practices without sacrificing the quality of the diagnostic test.

These changes, or potential for changes, from traditional practices indicate that there are significant demand-side management options that could be exercised that may not have been considered before. Suboptimal practices result in the overproduction of ^{99}Mo, with the related waste and safety concerns. With accurate pricing, the supply chain players could make a more appropriate assessment on the best way to supply and use ^{99}Mo/^{99m}Tc.

Additional capacity can increase supply, but it is not an economic panacea

Over the past year there has been much discussion and some action related to possible new projects that have or could come on line to support ^{99}Mo production. The use of the MARIA and LVR-15 reactors and the possible future use of other reactors are encouraging for addressing the short- to medium-term supply shortages.

However, it is important to note that these possible new projects could have a negative effect on the current economic situation. Depending on the remuneration provided to reactor operators and the related social contract with the host government, these projects could potentially be detrimental to the long-term economic sustainability of ^{99}Mo provision. If any new projects follow the historical remuneration model, paying only for the direct costs of irradiation with no or partial payment for the reactor investment costs directly related to ^{99}Mo production, it will be the responsibility of the host government to cover those costs not included. As a result, the continued production of ^{99}Mo will depend on the maintenance of the previous social contract with the host government.

This continuation of the historical unsustainable pricing structure could have important effects in the broader market. Those reactors that are required to operate commercially may not be able to sustain their operations in the long term, threatening the long-term reliability of the supply chain. As a result, these new sources of irradiation, given that they are mostly older reactors, could just serve to postpone the pending supply shortage. If the pricing structure perpetuates the current economic situation where new LEU-based ^{99}Mo production infrastructure cannot be constructed or maintained without government assistance, the issue will not be solved in the long term.

That being said, these projects are important for helping to alleviate the short- to medium-term shortages. If they implement pricing that encourages the economic sustainability of the industry, they will not only be crucial in setting the industry on the right price path but will also provide additional flexibility in the supply chain to give time for market changes to occur and new infrastructure to be developed.

Required changes for economic sustainability

Changes are needed to address market, policy and technological failures

Overall, the current economic situation points to the need for changes in the economic structure, and especially so if governments reduce their financial support for the industry. Before discussing how to make those changes, it is important to discuss what type of failures are occurring and then determine the proper action to address the failure.

A market failure exists if there is an inherent value of a product that is not being realised in the prices observed in the market as a result of some form of market operation barrier, including transactions costs from imperfect or asymmetric information, institutional failure, historical circumstances and/or market power. A policy failure exists where government initiatives to address concerns regarding market operations result in outcomes that create their own problems – at times resulting in an overall situation that is worse and leading to inefficient allocation of resources in the economy. A technology failure exists when a technology does not work and creates a significant disturbance in the market. The ^{99}Mo/^{99m}Tc market is subject to all of these types of failures.

- **Market failure**: Patients benefit from there being a reliable supply of ^{99m}Tc through having access to timely medical diagnostic imaging. Since the benefits may not be fully accounted for in the pricing structure, a positive externality exists. This positive externality should be addressed at the health care system level through reimbursement rates, not at the research reactor level.

- **Market failure**: Imperfect information related to the full costs of waste management, reactor operations, fuel consumption, etc. not being known or included in the price structure provides a significant deficiency in the pricing mechanism. In many cases the full costs for ^{99}Mo provision were not transparent to or appreciated by governments who were subsidising the production.

- **Market failure**: The existence of significant market power creates a barrier to developing a proper pricing mechanism for the efficient allocation of resources.

- **Policy failure**: The historical commercialisation route of the processing industry set the industry on the path toward unsustainable pricing and reinforced market power, resulting in the perpetuation of an uneconomical pricing structure and potentially inefficient use of ^{99}Mo.

- **Technology failure**: The development of new ^{99}Mo production capacity was stalled for a decade or more given the development of the MAPLES project in Canada, which was expected to have production capacity in excess of 100% of world demand. However, this project was cancelled by the Government of Canada in 2008. If this project had proceeded[4] there theoretically would have been sufficient capacity at the moment to meet global needs. However, the project could have created some other market failures if it had proceeded, including market power and reliability concerns as a result of the possibility of a single point of failure.

Prices must increase, but the impact on end users is small

Pricing for ^{99}Mo must reflect the full costs of production, the benefits of the product and the transportation and logistics. To do so, the pricing structure must change to include remuneration for necessary repairs, maintenance and finally replacement of the infrastructure. Without continued government support, the only way to make the industry economically sustainable is for it to operate on commercial terms.

To determine the magnitude of the price changes needed and their impact, levelised unit cost of ^{99}Mo (LUCM) calculations, based on information received from industry participants, were done to approximate the prices required for economic sustainability. The magnitude of these price increases were then applied to the supply chain to find the effect on the end user (the patient and/or the health insurance system). A number of capital investment scenarios were developed to compare different options available to the industry, with sensitivity analysis undertaken on discount rates, payback periods and the

4. Note that this paper is not presenting a view on the technology of the MAPLES project and its cancellation. This paper is only interested in the effect on the market.

amount of ^{99}Mo produced per week. The investment scenarios were based on the construction of a:

- Fully dedicated isotope reactor (FDIR).
- A multipurpose reactor where 20% of operations are for ^{99}Mo production (MP 20%).
- A multipurpose reactor where 50% of operations are for ^{99}Mo production (MP 50%).
- An existing multipurpose reactor (no capital costs) with 20 and 50% of operations for ^{99}Mo production.
- The above scenarios with processing facilities (Proc).

A separate scenario was not undertaken to determine the LUCM produced from a reactor that converted to using LEU targets because there is not yet a body of knowledge concerning costs and impacts of conversion on production, waste and the related economics at a major producer. New LEU-based reactors and processing facilities (Greenfield) would likely have similar capital costs to HEU production facilities, but may have increased operating costs per ^{99}Mo curie produced based on current target design. It is reasonable to assume that the conclusions related to the need for economically sustainable pricing and the impacts on the end user for production from HEU would continue to hold for production from LEU (either Greenfield or conversion).

It is not the role of the NEA to state what the price of ^{99}Mo should actually be within the supply chain. The calculated values should only be considered indicative of the pricing that would provide for economic sustainability relative to the prices calculated in the previous section and of the magnitude of changes necessary. They should not be construed as representing the situation exactly in any particular region or jurisdiction.

Calculating the LUCM values and applying these through the supply chain indicates that significant price increases are necessary in the upstream supply chain to be able to arrive at a situation of economic sustainability.

Even though the price increases are significant in the upstream supply chain, the analysis finds that there is very little effect on the prices that the end user would see, even assuming a full pass through of all cost increases. Irradiation services require a price increase from about EUR 45 (USD 60) per six-day curie EOP to a range of approximately EUR 55 to 400 (USD 75 to 555)

depending on the investment scenario, which is a maximum factor increase of about nine. In terms of the end user, the Table E.3 shows that the reactor share in the final reimbursement rates would increase from approximately EUR 0.26 per procedure at pre-shortage prices to between EUR 0.33 and EUR 2.39 under a situation of economic sustainability (with the lowest value related to an existing multipurpose reactor with no capital cost requirements and the highest value relating to the FDIR scenario).

Even at the most extreme price increase at the reactor level the value of irradiation would only be 0.97% of the final reimbursement rate for the procedure. When compared to the original 0.11% this is a substantial increase but when compared to the overall reimbursement rate of the procedure it is not very significant. In terms of the final impact of the price pass-through for the supply chain (including the required price increases at processing facilities), the impact of the increased radiopharmacy price on the final reimbursement rate is minimal, increasing from 4.42% of the reimbursement rate to a maximum of 5.69%.[5] This, of course, assumes that the *absolute cost increases* are passed through, not percentage increases.

Table E.3: Impact of price increases at hospital level*

	Irradiation value within final radiopharmaceutical price EUR	Irradiation value within final radiopharmaceutical price USD	Irradiation value as % of reimbursement rate
Current situation pre-shortage	0.26	0.37	0.11
FDIR	2.39	3.33	0.97
MP 20%	0.85	1.18	0.35
MP 50%	2.12	2.96	0.86
MP 20% – no capital costs	0.33	0.47	0.14
MP 50% – no capital costs	0.84	1.16	0.34

* As with all values presented in this report, these values are meant to be illustrative of the situation being described and should not be construed as being the absolute true value. The scenarios with processing capacity are not presented here as they do not impact the irradiation values within the final prices. Table 5.7 in the full report provides the impact of investment scenarios that include new processing capacity.

5. Not shown in Table E.3 but presented in Table 5.7 of the full report.

The demonstrated small impacts indicate that the downstream components should be able to absorb these price increases. However, this issue may require further study and possible assessment by hospitals and medical insurance plans, especially in the context of continued downward pressure on reimbursement rates or where the health system provides fixed budgets to hospitals for radioisotope purchases.

The impact on the end user of converting to LEU targets is also quite small, even through the price impact upstream could be quite significant. Simulating conversion under a situation where the density of the uranium in the targets cannot be increased significantly can be done by looking at the difference in the calculated LUCM between the investment scenarios for the 20 and 50% ^{99}Mo-attributed multipurpose reactors. The end result on the patient is quite small, with the radiopharmacy price going from 5.06% to 5.58% of the final reimbursement rates and with the share of the irradiation services in the final reimbursement rate going from 0.35% to 0.86%.[6]

There was concern raised by some market participants that if irradiation prices increased substantially, there would be too much of a financial strain on companies further downstream. The analysis shows that while the required price increases throughout the supply chain could be considered significant, the end effect on the end user is very small and thus the supply chain should be able to absorb the price increases.

Creating a pricing system that covers the full costs of production should also reimburse for the local impacts of production for the global market, including radioactive waste management, that are currently being subsidised by the domestic taxpayer.

Reserve capacity needs to be funded

With effective coordination of reactor and processing production schedules that allows for the optimal use of operating reactor capacities, one would expect that the WRC component of total reserve capacity would result in an annual supply capacity equal to the annual amount of product demanded. However, a lack of effective coordination could result in excess capacity. Historically, this has been the case and has resulted in prices being driven below economically sustainable levels, especially given the situation of processor buying market power that existed.

6. Again, not shown in Table E.3 but presented in Table 5.7 of the full report.

For ORC there would need to be some annual excess capacity as one or more reactors may have to be shut down for an extended period. In order to have ORC available, there has to be a mechanism to recognise its value and financially support its capacity development, its availability and the action of *not* using the capacity when it is not necessary. The level of remuneration to reactor operators for holding reserve capacity should be less than the actual amount received for production since variable costs of production would not need to be covered. However, there would have to be sufficient reimbursement to cover the attributable portion of capital costs and overhead costs of the facility.

If this value is not recognised and remunerated, there will be a tendency for reactor operators to use the capacity to gain revenue rather than leaving it idle (i.e. as empty channels when the reactor is operating). The consequence of this would be to drive down the prices of irradiation services and perpetuate the market power at the processor level (since they would be able to go elsewhere for irradiation services without another customer stepping in to take their place).

Without WRC and ORC, the supply chain would not be reliable, creating ongoing supply uncertainties that greatly affect the ability to deliver quality health care. This reserve capacity must be available when required, with the full supply chain ready and able to respond, including having all regulatory approvals in place for operation, transportation and use of the ^{99}Mo/^{99m}Tc. As a result, the best option to ensure technical readiness would be spread reserve capacity among research reactors and processors by not using their maximum ^{99}Mo irradiation and processing capacity. In all cases, the provision of reserve capacity and the appropriate use of the capacity (i.e. not using it when not required and using it if required) must be enforceable through contractual agreements, and the coordination of the reserve capacity must respect all appropriate competition regulations.

As new reactors and processors enter the market they will have to voluntarily join these coordination efforts in order to avoid the situation of creating excess capacity and the resulting depression of prices. If this voluntary coordination does not work, governments may have to consider requiring those supply chain participants that operate in their jurisdiction to participate in coordination efforts. Of course, this coordination role should by no means be used to restrict available production to levels below expected demand in order to increase prices beyond what is commercially required.

Recognition of the value of reserve capacity does not necessarily have to be at the reactor level; it could also include demand management practices.

Demand management, including demand shifting, can provide an additional source of "supply" and reduce the need to develop capacity.

There has been experience gained from the structuring of liberalised electricity markets to ensure the existence of reserve capacity and to pay for that reserve capacity (such as through energy-only markets or capacity measures). However, the ^{99}Mo and electricity markets are not identical, so although common lessons may be learned, identical replication of mechanisms is not necessarily feasible.

Things are starting to change

The current shortage has disrupted the market and provides an opportunity to correct historical problems, moving toward a more economically sustainable market structure. For example, some of the barriers to entry at the processor stage discussed previously have been effectively reduced or removed, allowing others to enter the market and reduce the market power (although these have not been completely eliminated given existing contracts). The shortages have also convinced bulk ^{99}Mo clients that they should be multisourcing so that their supply is not subject to a single point of failure.

In addition, with the revived interest in nuclear energy there is an increase in demand for irradiation services for material and fuel testing at the major research reactors, reducing the market power of ^{99}Mo irradiation service purchasers (the processors).

The overall effect of the reduction of market power has resulted in reactor operators and other processors being able to gradually increase prices of ^{99}Mo toward more commercially sustainable levels. The shortages have reportedly stopped the price wars (at least temporarily) and diversification strategies have allowed for prices to increase.

There has also been an increase in downstream prices, partly as a result of the low margin pricing models being replaced by more appropriate pricing of ^{99}Mo at the generator stage of the supply chain, an effect that had already started before the present shortages. These price increases have not necessarily resulted in increased remuneration to reactor operators but have increased awareness of the value of ^{99}Mo, with supply chain participants indicating that there is greater acceptance of rising prices.

However, it is not clear whether the price increases that are starting to happen will be able to be maintained once the technical issues related to short-term supply reliability are resolved and short-term capacity increased. In order

to ensure that these changes are sufficient and continuous there are actions that still need to be taken.

Recommendations and options

Defining government role in financially supporting the industry

The first thing that needs to be done is for governments to assess their role in respect of the industry, especially related to the level of subsidisation provided to the upstream ^{99}Mo supply chain (reactors and in some cases the processors). This is predominately a policy decision rather than an economic one. As a result, this study is not recommending what a government should define as its social contract but only that the government should define their position and should ideally harmonise their approach with that of other producing nations. When industry has the impression that governments will continue to subsidise the ^{99}Mo supply chain, they will be less accepting of a change in the price structure and may delay possible investments as they wait to see the final government direction.

The options for defining the social contract are based on the expected role of the government and the degree of financial support that they are willing to provide to the industry. The three options available are based on the traditional model, a modified traditional model and a commercial model:

- **Traditional model**: government would build the required reactors and would irradiate targets for the processing component of the supply chain; the reactor operator would continue to charge only for direct marginal costs. This social contract would require continued government dedicated funding, including replacement costs when necessary.

- **Modified traditional model**: government would again build the reactor and irradiate the targets for the processing stage of the supply chain and not charge for any significant capital replacement costs. However, market pricing would include remuneration for costs related to maintenance, upgrades, share of total reactor operating costs/overheads and waste. The government would be required to fund the infrastructure development but the reactor should be able to *operate* on a commercial basis.

- **Commercial model**: the portion of the reactor facility that is attributed to ^{99}Mo production would be funded on a completely commercial basis, with all costs covered by market prices, including

the attributed portion of the capital costs (or replacement costs) of the reactor. The government would not have to commit significant resources to capital development or continued operation of the reactor for ^{99}Mo production, removing concern about subsidising production and waste management through taxes. However, governments would still have to fund the other non-commercial uses of the reactor.

The commercial model does not result in the government abdicating any responsibilities it has to providing health care to its citizens. Governments may decide to continue to pay for the use of ^{99m}Tc through increasing health insurance reimbursement rates (which are currently falling in many jurisdictions). This is a more appropriate place to subsidise the supply chain as it ensures the continued supply of ^{99m}Tc without specifying how it is produced, thus avoiding governments needing to pick technology winners. This would enable alternative technologies, if they are economical and efficient, to enter the market freely while recognising the positive externalities of nuclear medicine.

Once defined, governments should demonstrate their social contract through a strong, clear signal and committed actions such as removing subsidies, defining a transition period for removal of financial support or committing specific funding to the ongoing operation and capital development of reactors for ^{99}Mo production. This signal must include an ongoing political commitment to *not* intervene in the market even if there is public pressure to do so. In all cases, producing nations should make every effort to harmonise their approaches to avoid creating distortions between regional markets and to ensure that commercial-based production can continue to exist.

Paying for the full costs of ^{99}Mo production and capacity

Regardless of the definition of the social contract, the reactor operator must be remunerated for the full costs of ^{99}Mo production. These full costs include a share of common reactor costs and a reasonable share of the capital costs of the production facility or replacement costs. Where this remuneration will come from – through government direct support to reactors or from downstream supply chain participants through the pricing structure – will depend on the definition of the social contract in each country.

If the social contract is defined such that governments will continue to support ^{99}Mo production, they need to be willing and able to increase *ongoing* remuneration to reactor operators. In the current supply chain, additional LEU-based supply capacity and any related processing capacity is needed to account for ageing reactors and international commitments. As a result, governments would be required to provide funds for this capital investment.

Government funding could take the form of unilateral or international funding arrangements. The latter could be subdivided into directly funding a specific project through multilateral efforts or creating an internationally managed "fund". All of these arrangements would need to support ^{99}Mo production either through the traditional model or the modified traditional model.

The internationally managed fund could be supported by consuming nations paying a fee proportional to consumption. This option avoids potential free-riders as the support to the fund is based on consumption, not production. The problem of this option will be its enforceability – ensuring that consuming nations provide the funding required for the fund. In addition, It is recognised that implementation of any international funding mechanism would be extremely difficult.

If the social contract is redefined such that ^{99}Mo production infrastructure would be developed and operated under a commercial model, then more appropriate market prices will be required to cover the full costs. The pricing structure that will need to be demanded by reactors will require a substantial increase in prices and the maintenance of these higher prices once the current shortage situation is resolved. Such a move towards commercial-based pricing would have to be reflected in industry contracts over time, providing for a better operating market.

Various options exist on how to deliver the revised pricing, including: levelised cost pricing; levelised cost pricing with a fixed component; and access fee and service fee. These methods differ in delivery, but should be equal in terms of the present value of the remuneration to the reactor:

- **Levelised cost pricing**: price is based on expected production and full costs, including capital costs, with no guarantee of minimum funding as remuneration would be based entirely on the amount of the product produced and sold.

- **Levelised cost pricing with a fixed component**: pricing structure contains remuneration through a fixed component for service provision and then a variable cost for production. This would provide the reactor operator with a guaranteed minimum price covering fixed costs.

- **Access fee and service fee**: pricing structure would require customers of irradiation services to provide upfront funding to the portion of the capital investment that is related to ^{99}Mo production. This funding would guarantee the customer access to the services provided by the

infrastructure, with some guaranteed minimum amount of irradiation service. A service fee would be paid for units of ^{99}Mo actually produced, based on the full variable costs of production.

In some discussions, stakeholders have suggested that regulating prices is another option for increasing prices for irradiation services and processing. This option is less appealing and would be much more complicated than moving towards full-cost pricing. If pricing was commercially set at a level that would be economically sustainable – based on a clearly defined social contract – pricing regulation would not be necessary. In addition, the regulation of prices across international borders presents its own difficulties that would likely be prohibitive to undertaking such regulation.

The challenge will be to develop a harmonised framework that will allow transition to full-cost remuneration in a period when there are both old and new reactors, some with HEU and some with LEU targets and where there will be a number of operators of older reactors that have the incentive to maximise revenue before closure of these reactors. One option to address harmonisation under these conditions would be to develop a panel of experts from producing countries (or an international body) to review the market and provide a view on whether producers are applying the agreed upon social contract (e.g. full-cost pricing) or have clear plans to do so.

It is clear that if there is not ongoing financial support from governments, commercial pricing is necessary for the continued supply of reactor-based ^{99}Mo in the medium to longer term and the conversion to LEU-based production. A commercial-based pricing structure would have the added advantage of allowing for the accurate assessment of the value of ^{99}Mo and its production by research reactors in the health community. It is likely that the benefit of ^{99m}Tc based nuclear imaging testing would allow for the absorption of cost increases downstream and a move to encourage medical insurers to increase reimbursement rates for these types of procedures. However, another possible outcome would be the increased development and use of alternative imaging techniques; increased demand-side management to use the product more efficiently; and increased development and use of alternative means of producing ^{99m}Tc, all where economically viable.

Paying for reserve capacity

It is clear that reserve capacity is required for a reliable supply of ^{99}Mo/^{99m}Tc and that coordination and effective communication through the supply chain is essential to ensure the appropriate use of reserve capacity and to

reduce impacts of unplanned outages or longer-term planned outages. However, these efforts do not respond to the need to pay for reserve capacity. Funding is principally important for the provision of reserve capacity that serves the purpose of dealing with unplanned outages (ORC).

If governments decide to maintain their historical role of supporting the development and maintenance of reserve capacity, given the desire for security of supply, then they would have to commit to funding the provision of ORC at reactors and any related processing facilities. As with the overall capacity, government funding could be provided unilaterally by the national government responsible for the reactor or through a form of international government funding.

Under both of these options, funding for reserve capacity could be supported through general taxes. Under unilateral actions, a government would support reserve capacity in their jurisdiction, but this capacity also provides *global* supply security. An export tax on exported ^{99}Mo could potentially be used to help reduce the amount of funds required from the general tax base. Under international funding, countries could support an international reserve capacity fund through their general tax revenues. This international fund would then provide support to the ORC that is deemed necessary to ensure reliable supply.

Another option would be to fund reserve capacity through a flat charge applied to the ^{99}Mo/^{99m}Tc supply chain. Under this option, a levy would be charged on each curie of bulk ^{99}Mo sold or each curie of ^{99m}Tc used in a nuclear medicine procedure. This could be collected by each country's government to pay for reserve capacity in their country, to support reserve capacity at reactors in other countries or to support the "international reserve capacity fund". Again, it is recognised that implementation of any international funding mechanism would be extremely difficult.

Under any of the above scenarios, if a government determines that their social contract includes financially supporting reserve capacity they have to be able to commit to *long-term ongoing* funding for that capacity. In addition, government must be aware that they will have entered into a social contract with the global supply chain to ensure that the capacity is available, operational, has regulatory approval and will not be used except in situations where it is necessary.

If the government defines a social contract that does not include any obligation to fund reserve capacity, the capacity would need to be supported through commercial funding. Since it is theoretically possible to exclude any non-paying party from receiving product from reserve capacity that they did not

support, it should be the clear role of the private sector to ensure that they have secured access to a reliable supply network and sufficient outage reserve capacity. In this case, the end users should demand reliable supply and be willing to support it through a "reliability premium". This demand and the remuneration should flow back up the supply chain, resulting in the upstream providing reserve capacity and being paid for it.

However, it is possible that the positive externalities of having a reliable supply would not be fully captured in the market and there may be a role for government intervention. If this occurred, governments could require that generator manufacturers and processors have access to ORC. Such a requirement could be delivered through a reserve capacity credit system.

Conclusion: Changes must occur for supply to be secure over the long term

The current economic structure of the ^{99}Mo supply chain does not provide for sufficient financial incentive to economically support ^{99}Mo production at existing research reactors or development of new LEU-based production and processing capacity. The historical market development and current pricing structure has other undesirable effects on the current economic situation, such as the potential inefficient use of ^{99}Mo and ^{99m}Tc and no recognition of the economic value of reserve capacity to deal with operational realities of reactors and unplanned outage situations.

It is clear that there is no single silver bullet that will set the supply chain on an economically sustainable path to reliability. It is highly unlikely that all governments and supply chain participants will be able to quickly decide on the social contract in a harmonised fashion and take the required steps to alter the market to reflect that contract. However, the long-term goal should be to arrive at a supply chain that is economically sustainable and not reliant upon the use of HEU.

A number of incremental changes could be taken to move toward realising that long-term goal. Governments could set a transitional period where they would continue to subsidise ^{99}Mo production and capacity development, gradually increasing the required amount of private sector contribution to these costs until full-cost pricing is achieved. This process would provide time to allow for the market to adjust to the new pricing paradigm but would require committed government funding through the period.

At the same time, governments could undertake a review of reimbursement rates for nuclear medicine diagnostic tests, focusing on the final impacts of a transition to full-cost pricing and how to manage the communication during and

post the transition. It is understandable that increasing reimbursement rates or hospital-specific isotope budgets takes time and, in some countries, requires the co-operation of multiple jurisdictions. As a result, the transition period to full-cost pricing is even more important to ensure continued financial support.

Supply chain participants need to realise that it is unlikely that the current economic model can support ^{99}Mo production in the medium to long term. Pricing models and contracts need to reflect the principles of economic sustainability. Supply chain participants need to support, not hinder, the required changes with the goal of sustaining the industry and benefiting patients.

It is clear that the changes discussed in this report are necessary for the economic sustainability of the ^{99}Mo/^{99m}Tc supply chain. There are a number of decisions that governments and industry players need to take, decisions that could have a long-term impact on the supply chain. If no actions are undertaken, the supply chain will remain fragile and require significant, ongoing government financial support. Harmonised action is required and it seems that the supply chain and decision makers are becoming aware of the issues and are willing to take action.

The NEA can help

The NEA will support these efforts by playing an ongoing role in encouraging a reliable supply chain during and after the transition period. Its role is to provide important and relevant information, economic analysis and options/recommendations on the market situation. It will also continue to serve as a forum for producing nations to discuss the issues and work towards solutions through the HLG-MR.

Following up on the findings of this economic study, the NEA will undertake further study to support the HLG-MR in discussing policy options. Through a series of background papers, the NEA will examine different market models and approaches to ensure sufficient capacity, including reserve capacity.

The full report is available at:
www.nea.fr/med-radio/reports/Mo-99.pdf

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