Editorial

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Commentary: supplies of molybdenum-99 – need for sustainable strategies and enhanced international cooperation

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The field of functional diagnostic imaging has been dominated by nuclear medicine procedures thanks to the excellent features of ^{99m}Tc – nuclear and chemical characteristics, as well as inexpensive and abundant availability [1–3]. The latter attribute – 'ease of availability' – has been in question as never before since the fall of 2007 because of serious disruptions in supplies of the precursor nuclide, molybdenum-99 (^{99}Mo), which has stretched until February 2009. The vulnerability of irradiation services from the five old research reactors (RR) used for ^{99}Mo production, compounded by certain other (unrelated) incidents, has led to approximately 20–70% cancellations or delays in patient services depending on the week and location of nuclear medicine centre [4,5]. The issues to be addressed in seeking sustainable solutions will, however, need to go far beyond the reactors. It is true that the current problems are related mainly to the reliance on five old reactors for irradiation of enriched uranium-235 targets for the production of fission-based ^{99}Mo, but there are other important issues that should not be overlooked. These include, *inter alia*, the complex and demanding technological issues in fission molybdenum production combined with the scale of operations for acceptable business/economic reasons, a multicomponent complex chain of supply logistics, conflicts of commercial interests among the limited number of current major producers some of them implicitly conveying discouraging signals to new entrants, and the important and inevitable concerns with regard to the continuing use of highly enriched uranium (HEU) targets for fission-based ^{99}Mo production [6]. It is imperative to consider all the above aspects in evolving holistic and long-lasting approaches to ensure reliable and secure supplies of ^{99}Mo for the immediate future and for long-term requirements.

This Commentary is an invited contribution and reflects the Author's professional views conveyed in a personal capacity. It is partly drawn from an Award Oration delivered in New Delhi, India, on 1 November 2008. The views are not necessarily those of the IAEA or of the journal *Nuclear Medicine Communications.*

Recent events and calls for addressing issues

The weekly requirement of ^{99}Mo is reported to be approximately 450 000 GBq at the time of reference (generally 6 days after the end of reactor irradiation) – that is, over 12 000 Ci (6-day Ci) – with almost 50% for the US market alone. The five reactors currently used for irradiations are NRU (51 years), Chalk River, Canada; BR2 (47 years), Mol, Belgium; HFR (47 years), Petten, The Netherlands; Osiris (42 years), Saclay, France; and SAFARI-1 (43 years), Pelindaba, South Africa. There are only four large-scale processing facilities for fission-based ^{99}Mo – MDS Nordion, Canada; IRE, Belgium; Covidien, The Netherlands; and NTP, South Africa. The reactors are also not dedicated to the production of ^{99}Mo and other radioisotopes, but provide services to other users and for research. Domestic production in the US was stopped long ago. The reasons for this are not known with certainty, but it could be the result of the comparative consideration of the costs involved in domestic reactor operations and the production of ^{99}Mo versus the purchase of the finished product from commercial sources in Canada and Europe.

The reliable and assured operation of the ageing RRs and allied support facilities is understandably a challenging task. The need to ensure compliance with mandatory safety regulations in all applicable areas can be well appreciated by the professional community of end users in medical centres and radiopharmacies. The apparent buffer capacity in ^{99}Mo production will always be under severe strain, particularly when either of the larger production facilities, that is, those in Canada and The Netherlands, is shut down, as occurred at the end of 2007 and through the second half of 2008. The ^{99}Mo supply chain will continue to remain fragile in the foreseeable future because the number of reactors actively engaged in irradiation services as well as facilities for ^{99}Mo processing would be major limiting steps. The only additional capacity expected in 2009 is from the OPAL reactor and ANSTO, and their entry, envisaged in mid-2009, is crucial for more than one reason. Two new initiatives have

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emerged in the US, one from the University of Missouri Research Reactor (MURR) and the other from The Babcock and Wilcox Company (BWXT; later joined by Covidien), but these will not add to practical capacity for at least the next 4 years. Simultaneously, there are increasing concerns with regard to the long-term security of supplies, as no new facilities are on the horizon, - with AECL announcing the termination of the MAPLE reactors in May 2008 and no other new reactors expected until 2015 at the earliest (JHR, Saclay/France). The relicensing requirement of NRU in 2011 and the expected shutdown of OSIRIS in 2015 cast a dark shadow, while the proposal for a new Dutch reactor (PALLAS as HFR replacement; cost: approximately 300 million €) and the Belgian neutron facility (as BR2 replacement) MYRRHA, or an updated version of an earlier proposal called ADONIS, are yet to secure assured funds.

It would be highly appropriate to acknowledge the excellent services being rendered by the current major manufacturers of ^{99}Mo over the past several decades. At the same time, it is necessary to urge them to be sensitive and responsive to emerging international situations that stretch well beyond the realms of normal corporate spheres. A shift in their stand is necessary in two cases, namely, additional production capacity required to enhance the reliability of supplies of ^{99}Mo and LEU conversion (discussed later).

The cascade of events in 2008 affecting ^{99}Mo supplies has resulted in a number of international meetings/events to consider possible strategies to enhance the reliability of supplies of ^{99}Mo and the sourcing of ^{99}Mo from other routes. The Third Research Coordination Meeting (RCM) of the IAEA CRP on 'Developing techniques for small scale indigenous ^{99}Mo production using LEU fission or neutron activation' held at MURR, USA in October 2008 virtually turned into an international seminar, with a number of industries and governments interested in ^{99}Mo production and/or of ^{99m}Tc generators opting to join the RCM. More than 20 observers, including representatives from industries and governments interested in ^{99}Mo production and ^{99m}Tc generators, the US Society of Nuclear Medicine and US-National Academies, were in attendance. A team of representatives of the European Association of Nuclear Medicine (EANM), that visited Brussels in September 2008 for discussions with relevant European Union (EU) authorities to highlight medical needs and seek support for assured supplies, is pursuing the matter with the EU. The EANM also established contact with the IAEA to share concerns and seek support, and held a side discussion in October 2008 during its annual meeting in Munich. The Association of Imaging Producers and Equipment Suppliers has completed a survey and released in November 2008 a report on ^{99}Mo Production for Nuclear Medicine 2010–2020 [5]. Details of another recent survey conducted by the Dutch Nuclear Medicine Society can be requested through the EANM Secretariat (*www.eanm.org*).

In a meeting held in San Antonio, Texas, USA, in December 2008, the International Nuclear Regulators Association discussed issues related to the supply of medical radioisotopes, and ^{99}Mo in particular. The French Nuclear Safety Authority (ASN) invited counterparts from seven other countries with radioisotope-producing reactors – Australia, Belgium, Canada, The Netherlands, South Africa, the UK and the USA–to a meeting in January 2009 to discuss how to maintain a sufficient safety level at the reactors deployed for the large-scale production of radioisotopes. In both meetings of regulators, the concern was that extended, unplanned outages of reactors could result in regulators being asked to balance difficult health and nuclear safety concerns. The need for government support and additional investment was also cited. At the request of the Government of Canada, the OECD-NEA in Paris, in cooperation with the IAEA, organised a Workshop on 'Security of supply of medical radioisotopes' in the last week of January 2009. Most stakeholders in the ^{99}Mo–^{99m}Tc business attended, but many from non-OECD countries were not present. The Chair's Summary has already been widely distributed [7], while further actions were discussed at the NEA Steering Committee Meeting at the end of April 2009. There were a number of key points analysed at this meeting, such as problems faced by reactor managers and their governments, as the facilities are not exclusively dedicated to the production of isotopes; inadequate financial incentives to RR managers; huge costs and long lead time in building new facilities; issues of denials/ delays in shipments likely to aggravate the already fragile chain; and scope of increasing the effective use of ^{99m}Tc generators. However, there was, unfortunately, very little coverage of the imminent additional capacity of ANSTO in 2009, and no attention to or interest in making greater use of existing production capacity on a smaller scale (e.g. CNEA/Argentina, BATAN/Indonesia) outside the major industrial producers. The scope of encouraging potential new producers who are either setting up facilities (e.g. EAEA, Egypt) or have appropriate facilities and capabilities (e.g. POLATOM, Poland) was also not considered.

An interesting parallel development has been the conscious realisation of the scope of enhancing the effective use of every ^{99m}Tc generator. This is done by way of more effectively using the generator throughout its shelf-life period, in terms of a greater number of daily elutions, sharing of generators between users, and according priority in supplies to central radiopharmacies (at times of shortages) to cater to a greater extent to as many end users as possible. The second, and perhaps more fundamental, adjustment has been how to use ^{99m}Tc for the studies/patients most in need, rather than following 'appointment calendar' schedules. It is not that any inconvenience caused to pre-scheduled patients is acceptable, but to really accord due recognition to the use of ^{99m}Tc for truly valuable or unique contributions in clinical decision making. It is necessary to avoid 'cries of life-threatening cases' but cite 'avoidable denial of high benefits from an elegant diagnostic imaging modality' for much more efficiently and objectively managing patients of certain clinical conditions (i.e. supporting evidence-based decision making process). The use of ^{99m}Tc clearly belongs to the latter category, but nonetheless warrants, on merit alone, all the support and attention it can get, to be reliably available to patients everywhere in the world. In explaining matters to the media and the decision makers in national governments and multilateral bodies such as the EU, an objective analysis of situations in which ^{99m}Tc imaging is really critical for patient management has emerged. The extent of the practice of nuclear cardiology in the US, although unique, cannot be fully met by PET myocardial perfusion imaging (e.g. using $^{82}Rb^{+}$ obtainable from ^{82}Sr/^{82}Rb generator). If this is the case in developed countries such as the US, it goes without saying that the importance of ^{99m}Tc-based myocardial perfusion imaging elsewhere (estimated to be up to 60% of all imaging performed with ^{99m}Tc) cannot be overstated. Thallium-201 is the cyclotron-produced alternative for myocardial SPECT imaging but has drawbacks in terms of decreased image quality and higher radiation dose. The main method of bone metastasis imaging uses ^{99m}Tc-MDP, including in developing countries, and cannot be completely replaced with ^{18}F-fluoride PET scans. The other high-impact applications that will suffer, if adequate and ready availability of ^{99m}Tc is not present, are unequivocal confirmation of pulmonary embolism by lung perfusion scan in an emergency setting, precisely delineating the lesion mass to be removed by surgeons while operating on breast cancer patients, and differential diagnosis of aseptic loosening of prostheses versus infected prostheses in patients with joint replacement. The stories in the media have been expectedly mixed, but professional medical opinion is notable on such topics as the major or unique utility of ^{99m}Tc imaging in supporting evidence-based patient management.

Uranium-235 targets for ^{99}Mo production

The dependence on HEU targets (by definition more than 20% ^{235}U; typically up to 93% enriched ^{235}U is used; 45% enriched ^{235}U target is used in South Africa) for more than 95% of ^{99}Mo production (which involves the use of 40–50 kg HEU per year) has been a matter of serious concern in view of nuclear security and proliferation risks. Since 2002, the Nuclear Energy Commission of Argentina (CNEA) has been producing ^{99}Mo using LEU dispersion plate targets (700–800 Ci per week at time of production). In the second half of 2009, ANSTO is expected to become the first large-scale ^{99}Mo producer using LEU, that is, with a production capacity of over 1000 Ci (6-day Ci) weekly lots. The current major producers of ^{99}Mo have aired varied views on using low enriched uranium (LEU, i.e. $< 20\%$ ^{235}U) targets, while some are not yet ready to acknowledge the LEU technology as adaptable. Surely it is necessary to have the buy-in of all stakeholders in this matter.

The US National Academy of Sciences (NAS) under congressional mandate in 2005 organized a feasibility study of LEU use. This was done consequent to the congressional approval to grant an exemption (Burr Amendment in the National Energy Policy Act of 2005) so as to continue to make available HEU to a few select recipients for production of ^{99}Mo (to overturn the 1992 Schumer Amendment requirement) and the simultaneous requirement to institute an NAS study. Accordingly, during 2006–2008, a committee of 14 experts (which included two senior expert nuclear medicine physicians, Dr Steven M. Larson and Dr Richard C. Reba) performed the study on 'Feasibility of procuring supplies of medical isotopes from commercial sources that do not use HEU'. The US-NAS Study Report findings and recommendations were under review in the fall of 2008 and were made public on 14 January 2009 [8]. The executive summary is available at *http://www.nationalacademies.org/*, while the full text of the Report is detailed and comprehensive, and is extremely significant for sustainable production and supplies of ^{99}Mo. The Report reflects well the need for actions and support from all stakeholders including governments, and international cooperation to address the LEU conversion issues. There are specific steps recommended for consideration by the US Congress, such as cost sharing for conversion-related R&D; conditioning the supply of US-origin HEU for medical isotope production – 7 to 10-year phase-out date for HEU exports; and government assistance likely to be required to improve supply reliability. There is considerable need for cooperation and support from many quarters, including national governments and technology developers; also needed are adequate finances and other resources, as well as appropriate planning and scheduling of transition/conversion over a period of time, along with adequate enhancement of production in other facilities. It can be inferred from US sources that it is only a matter of time before the supplies of HEU for civilian applications will dry up, and in that case, ignoring conversion issues may severely jeopardise the future of ^{99m}Tc-based diagnostic SPECT imaging in nuclear medicine.

Preceding the release of the NAS Report, under the Global Initiative (GI) to Combat Nuclear Terrorism (GICNT), 50 participants from 14 countries representing industry, national reactor centres, government, end users and the IAEA met at a workshop in Sydney in December 2007 (cohosted by NNSA-DOE, USA and ANSTO, Australia) and drafted a report detailing, among other things, the technical, economic and political aspects and requirements to be addressed for the adoption of and conversion to the use of LEU targets [9]. The salient points emerging from the GI Workshop Report were presented to the participant governments in GICNT to explain the status and mobilise appropriate support for conversion.

(1) There are no scientific barriers to the production of ^{99}Mo using LEU; small-scale to medium-scale production has already been demonstrated.
(2) The issue is one of the technical feasibility of LEU target process vis-à-vis commercial demonstration of regular large-scale production capability.
(3) Converting HEU ^{99}Mo facilities to LEU ^{99}Mo requires a long lead time and resources; this could take 8 years or more.
(4) Adaptation of the LEU process by fresh entrants, 'greenfields', and conversion of existing facilities using the HEU process, 'brownfields', will involve different paths and requirements.

The IAEA is implementing activities to foster the use of LEU targets and to help identify and expand the number of reactors engaged in the production of ^{99}Mo for better reliability/sustainability. These include coordinating research (CRP, 2005–2010) on 'Developing techniques for small scale indigenous ^{99}Mo production using LEU fission or neutron activation' [10,11]; encouraging potential facilities to become actual producers (e.g. Egypt); and establishing RR coalitions to expand/strengthen a network of reactors capable of providing irradiation services (e.g. Poland, Romania). The IAEA CRP comprises several participant countries with the potential to become small-scale to medium-scale ^{99}Mo producers using LEU targets as evident from either physical progress, for example in Chile, Egypt and Pakistan, or noticeable advanced plans, for example in Libya and Romania. Some of them at least could become part of the international ^{99}Mo supply network, especially if supported and sponsored by the current major producers, as a way of enhancing the capacity and attaining accessibility to more reactors. Egypt and Pakistan are known to be setting up full-fledged facilities for the production of LEU fission-based ^{99}Mo involving industrial help of INVAP, Argentina and Isotope Technologies – Dresden (ITD), Germany. This should be an attractive incentive for at least some of the existing producers to seek commercial partnership proposals. The IAEA support for strengthening the operational reliability of RR and the networking coalition of RR is also aimed to help in enhancing the reliability of radioisotope supplies in general and of ^{99}Mo in particular.

Alternative options for ^{99}Mo production

(1) Aqueous homogeneous reactors: The basic aqueous homogeneous reactors (AHR) concept studied in the past, and there are at least 30 facilities reported, has been revived by BWXT, USA and may lead to an alternative option in future for short-lived fission-based radioisotopes, and especially ^{99}Mo. The AHR will use uranium (LEU) salt solution as both fuel and target, and at periodic intervals one can recover (off-line) fission products such as ^{99}Mo (as also ^{131}I and ^{90}Y) from aliquots of fuel solution that are drawn out. The advantages include less complex requirements (cf. full-fledged reactor), certain inherent nuclear safety features of negative reactivity coefficients and relatively lower costs of installation and operation [12]. The conceptual plan of BWXT cites a 200 kW system that can yield about 1100 (6-day) Ci of ^{99}Mo per week (modular basis; additional units for enhancing production capacity). The strategy and the industrial efforts envisaged involving BWXT–Covidien cooperation obviously hold promise as a new approach, even though several issues related to separation process, corrosion, uranium fuel clean-up, and waste handling are yet to be addressed to the satisfaction of the operators and regulators. In July 2008, the IAEA launched a new CRP on 'Feasibility Evaluation of the Use of LEU Fuelled Homogeneous Aqueous Solution Nuclear Reactors for the Production of Short Lived Fission Product Isotopes' with a relatively small team that will study certain relevant aspects of LEU solution-based AHR [13].
(2) High-power accelerator and photo fission of ^{238}U: The Task Force on Alternatives for Medical-Isotope Production met in Canada in November 2008 and elaborated on an novel route of photo-fission of ^{238}U for the production of ^{99}Mo. Their report is available on the web [14] while there is a Note in the Opinion Column of 'Nature' by Dr Thomas Ruth of TRIUMF [15]. The extremely low cross-section of the reaction route proposed is sought to be tackled using very high-intensity photons from the accelerators of MW-level power. Considerable R&D and large resources are required to assess the potential of this approach, and it will take several years to complete technology development and assessment, let alone address the challenges in the development and sustained operation of very high-power accelerators on a reliable and continuous basis.
(3) Revisiting (n,γ) ^{99}Mo and using enriched ^{98}Mo: Neutron activation of MoO_3 targets at a neutron flux of more than 5×10^{13} n/cm^2/s is used to a small extent for ^{99}Mo production. This (n,γ) ^{99}Mo is used as zirconium molybdate gel to obtain ^{99m}Tc in China, India and Kazakhstan [16,17]. In the OECD-NEA Workshop, Japan and the Republic of Korea (ROK) announced their plans to revisit the (n,γ) option to partly meet domestic requirement. The use of

special high-affinity sorbent, such as the Japanese poly zirconium compound (PZC) pursued earlier under the scheme of the Forum for Nuclear Cooperation in Asia, should be mentioned in this connection [18]. An analogous sorbent poly titanium oxychloride is reported by Le Van So *et al.* [19].

In Uzbekistan, the enriched ^{98}Mo target is used in a flux of 1–2 $\times 10^{14}$ n/cm^2/s and ^{99}Mo of medium specific activity formed is shown to be adequate for preparing (relatively larger) alumina column ^{99m}Tc generators. It is possible to conceive of an approach to using enriched ^{98}Mo targets to produce (n,γ) ^{99}Mo in reactors with a neutron flux of $8\times10^{13}$to 2×10^{14} n/cm^2/s for alumina column generators and recovery of enriched ^{98}Mo from spent generators for recycling. It can be shown that building an initial inventory of about 200 kg of enriched ^{98}Mo should suffice for sustainable supplies to meet a considerable part of the medical requirement [20]. The prospect of using ^{99}Mo obtained for modest-capacity generators, as well as for higher-capacity generators by mixing ^{98}Mo $(n,\gamma)^{99}$Mo with an appropriate quantity of fission-based ^{99}Mo is deemed worthy of consideration. The reactors available in many countries and the nature and cost of facilities to be set up for ^{99}Mo production are appealing. This can provide another option in future that is less demanding and relatively less expensive.

In the past, the author exchanged a radical idea during discussions with colleagues at BARC, Mumbai, who were working on laser-based isotopic enrichment of ^{13}C and other similar nuclides of interest (personal communication with Dr V. Parthasarathy and other colleagues in Laser and Plasma Technology Division, BARC, Mumbai). The idea was to explore whether it would be feasible to (relatively rapidly) isolate microscopic amounts of radioactive ^{99}Mo by mass separation from a neutron-activated bulky mass of targets of molybdenum compound. The main rationale was that the quantity of molybdenum-99 to be separated would be, in this case, at milligram levels and thus much more amenable to known enrichment strategies. This was, however, deemed technologically difficult because of the unfavourable features of the chemistry of molybdenum compounds for laser-based approaches, both by the atomic and molecular routes. It is hence interesting to note some recent web reports on the prospect of production of ^{99}Mo of higher specific activity by 'mass separation', and in the author's opinion this could perhaps be based on such an enrichment method. Technological advances in the use of lasers and other means of mass separation (enrichment) may allow the success of this concept, while the scale of production will be dependent on the practical limits of irradiation volumes and the capabilities of the mass separation (enrichment) facility. Some interesting developments are not ruled out.

The researchers at the Reactor Institute, Delft, The Netherlands, have reported developing a molybdenum compound to be used as target material for producing ^{99}Mo of high specific activity, making use of hot-atom chemistry (Szhilard-Chalmers process) [21] and have applied for a patent. The new target is, however, yet to be tested under high neutron flux and other harsh conditions typically encountered in the irradiation positions of the isotope-producing reactor. The volume of production made by possible by this route will be limited but could still be of interest and utility in meeting small-scale requirements.

The feasibility and economics of AHR and the photo-fission route (as well as the method of hot-atom route) will remain debatable, and these approaches are not likely to add to any significant production capacity in the near future. The scope of using enriched ^{98}Mo is relatively more appealing in this regard, especially if adequate support and technological attention are given to building an inventory of ^{98}Mo (about 200 kg), and to developing recovery methods to recycle ^{98}Mo from spent generators. This approach can supplement the current production capacity to a reasonable extent in the future.

Directions for the future

There is inadequate global buffer production capacity for ^{99}Mo, while short-term, medium-term and long-term requirements warrant different approaches and levels of support.

For the immediate future:

(1) The existing coordination and collaboration needs to be further strengthened among senior managers in charge of reactor operations, maintenance and regulatory matters.
(2) The scope of increasing the utility of every GBq of ^{99}Mo produced, and of every ^{99m}Tc generator, should be fully ensured, and this should include measures such as greater use of central radiopharmacies and satisfactorily addressing shipment denials and delays.
(3) Other than the four large corporate entities, there are a few producers, such as CNEA, Argentina and BATAN, Indonesia, that can contribute to regional needs to a limited extent and should be encouraged and supported in enhancing their production to the maximum extent possible.
(4) The ^{99m}Tc generator manufacturers have a requirement and are also in a better position to promote and support all possible additional ^{99}Mo production capacity likely to be available in the near future.

For the medium term:

(1) Concerted efforts are necessary to identify, encourage and increase the number of capable reactors currently available in different parts of the world to be fruitfully engaged in irradiation of LEU targets for ^{99}Mo production. Collaboration of current corporate producers with potential new sources should be strongly advocated and encouraged. At least one new additional facility for ^{99}Mo production based on the LEU target process is necessary, preferably in Europe, Central Asia or Northern Africa.
(2) It is worthwhile to explore expanding the fission-based production capacity with ^{98}Mo(n,γ)^{99}Mo using enriched ^{98}Mo target and the enlargement of the number of reactors engaged in ^{99}Mo production, as well as mobilising support for building an inventory of enriched ^{98}Mo stock and developing recovery-recycling methods for ^{98}Mo and addressing related logistics.
(3) When production centres of ^{99}Mo are better distributed geographically, favourable transport logistics and economy in freight costs will become available. One can then move away from the concept of '6-day Ci' to the more efficient and effective '3-day Ci' or '4-day Ci'.
(4) The imminent non-availability of HEU for civilian use cannot be wished away; honest and genuine efforts are necessary to adapt to using LEU targets and planning for conversion and coordination without affecting patient services. Resources and cooperation are necessary over the next several years.

For the long term:

(1) Support for planning and funding requires special attention for meeting long-term demands of not only ^{99}Mo, but also many other important reactor-based radioisotopes, including those used in radionuclide therapy. Additional availability of or access to new reactors might take several years, and is not likely before 2015.
(2) Possible progress in alternative options for the production of ^{99}Mo, such as AHR, the high-power accelerator route and the 'active mass separation (enrichment) process', could lead to augmentation of reactor-based production capacity.

Conclusion

A much higher degree of reliability for reactor availability is of utmost importance in the future to obtain the established or practical capacity in ^{99}Mo production on a routine basis. Old reactors in use will increasingly pose maintenance challenges, and, consequently, loss of access to a reactor will remain a question to be addressed. Engaging a greater number of reactors for irradiation would help to minimise the impact of any prolonged/sudden shut-downs of a serving reactor.

Furthermore, HEU availability is, and will remain, a state-controlled matter. In response to the medical community's concerns and those of ^{99}Mo-producing industries, the US Congress accepted the Burr amendment introduced in 2005, and, in parallel, launched the NAS study on LEU feasibility. The NAS study not only engaged all the stakeholders, but also had the representation of two senior nuclear medical specialists in the study team. The likely time scale and costs involved are also discussed in the NAS Report, apart from alerting about the need for national support. It is quite likely that the US Congress will make a decision on implementing the recommendations in the fall of 2009, or some time soon thereafter. Further, the entry of ANSTO, Australia, as a large-scale producer of ^{99}Mo using LEU technology is expected by mid-2009 and this will be a key signal of the practicability of LEU technology. In view of these developments, the need to plan for LEU conversion should be viewed as a practical necessity, to be implemented stage-wise in a progressive manner, to continue to avail the benefit of ^{99m}Tc-based imaging without interruptions. The IAEA as global facilitator can help to bring together all the stakeholders for objective analysis, and to catalyse necessary actions.

In response to the few paragraphs in the draft 2009 Nuclear Technology Report (NTR) of the IAEA submitted to the Board of Governors on the topic of problems faced in ^{99}Mo supplies, an extremely strong and positive response was received from the Board in its Meeting held in the first week of March 2009. The Member States urged the IAEA Secretariat to undertake necessary measures to ensure the reliable availability of adequate supplies of ^{99}Mo, and this gives a boost to the ongoing efforts of the IAEA Secretariat and enables the consideration of further actions, for example, facilitating stakeholders' efforts towards greater international cooperation, making sustainable services available to millions of patients across the world.

Fresh approaches along with new investments are required to help mitigate the consequences of situations affecting the healthcare systems of millions of patients and to continue to avail the benefits from the proven valuable utility of the ^{99}Mo–^{99m}Tc pair. Building a much higher buffer capacity in ^{99}Mo production, and conversion to the use of LEU targets, and/or deploying the enriched ^{98}Mo target, would impact the cost of ^{99}Mo and of ^{99m}Tc generators. However, it is pertinent to note that an increase in the cost of ^{99}Mo should only exert a partial burden on the cost of the ^{99m}Tc generator (which includes hardware costs, overhead costs, GMP costs, etc.), and even less on the cost of the final product,

^{99m}Tc radiopharmaceutical, used for patients (which includes kit costs, hospital radiopharmacy overheads, clinical services costs, etc.). It would be unfair to direct all the criticism to an inevitable cost increase in ^{99}Mo raw material as the only avoidable factor affecting the final cost of patient services. It is necessary to pro-actively and constructively engage decision makers and national authorities to achieve international cooperation among industries, reactor centres, end users and national governments to minimise the impact of cost increase.

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