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Future U.S. Supply of Mo-99 Production through Fission Based LEU/LEU Technology

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Abstract

Coqul Radio Pharmaceuticals Corp. (Coqul) has the goal of establishing a Medical Isotope Production Facility for securing a continuous domestic supply of the radioisotope Molybdenum-99 for U.S. citizens.
Coqul will use an LEU/LEU proven and implemented open pool, light-water,7MW,reactor design. The aim is a twin reactor facility for reliability with on-site hot lab chemical processing. In addition to medical isotope production, Coqul will explore the possibility of other applications such as silicon doping, other medical isotope production and also plans to perform and facilitate advanced neutron research.
In contrast to some of the competing novel technologies also aiming to meet the American medical isotope production needs, NRC licensing is unlikely to be a major obstacle given the modern, yet essentially familiar design. Given this reality, Coqul is optimistic that government and private funding will become available in the near future.

I. Introduction

Molybdenum-99 (Mo-99) and its decay product, Technetium-99m (Tc-99), the most widely used medical radioisotope, are used in life saving medical diagnostic imaging techniques which enable precise and accurate early detection and management of diseases such as heart conditions and cancer, all in a non-invasive manner. The imaging can significantly impact medical decisions, for example, by providing predictive information about the likely success of alternative therapy options or whether there is a need for surgical intervention. Furthermore, without this diagnostic medicine we would revert to the 1950's and alternatives to Tc-99 are very costly, especially to the U.S. patient.

Tc-99 decays by a process called "isomeric", which emits gamma rays and low energy electrons. Since there is no high energy beta emission, the radiation dose to the patient is low. The low energy gamma rays it emits easily escape the human body and are accurately detected by a gamma camera. The chemistry of technetium is so versatile it can form tracers by being incorporated into a range of biologically-active substances to ensure that it concentrates in the tissue or organ of interest. [1]

Tc-99 medical imaging techniques account for over 80% of all nuclear medicine procedures, representing over 30 million examinations worldwide every year. [1] The have half-lives of these isotopes are 66 hours for Mo-99 and 6 hours for Tc-99 and thus must be produced continually. Disruptions in the supply chain of these medical isotopes can suspend important medical testing services therefore the reliability of the suppliers is important. No significant supply of Mo-99 is produced in the United States; it relies mostly from production in Canada and Europe.

Historically, a series of research reactors commissioned between 43 and 53 years ago, produce 90 to 95% of the total global supply of Mo-99. Given the age of these reactors, there are issues related to their reliability with unexpected shutdowns occurring more often. The long years in use of the major producing reactors also raise issues related to reactor availability given the need of extended shutdowns for planned maintenance work and for unplanned maintenance. These reactors are expected to start reaching the end of their useful lives soon, the first ones are expected to permanently shut down by 2016, a trend that will continue in the future.

II. Developments

The United States depends mostly on foreign imports of Mo-99, thus it faces a potential crises were its citizens could face shortages of the lifesaving medical diagnostic Mo-99 and threaten the advancement of nuclear medicine. It is also confronted with the security risks of exporting highly enriched uranium (HEU); through the Global Threat Reduction Initiative the U.S. is promoting the use of low enriched uranium (LEU) for MO-99 production.

The American Medical Isotopes Production Act of 2012 (“ACT”) was approved as part of the 2013 National Defense Authorization Act for Fiscal Year 2013 (H. R. 4310). The ACT provides that the Secretary of the Department of Energy (“DOE”) shall carry out a technology neutral program to evaluate and support private sector projects for the production within the United States of significant quantities of MO-99 for medical use without the use of HEU.

As part of the program and pursuant to the ACT the Secretary of the DOE shall provide assistance for the development of fuels, targets, and processes, for domestic Mo-99 production methods that do not use HEU. In addition to the above, the Secretary shall establish a uranium lease and take-back program to make LEU available through lease contracts, for irradiation for the production of MO-99 for medical use (“Lease and Take-Back”).

Our company, Coquí Radio Pharmaceuticals Corp., has the specific goal of establishing a dedicated Medical Isotope Production Facility (“MIPF”) in order to secure a significant and continuous domestic supply of the radioisotope MO-99 for U.S. Citizens. The Company will use

LEU/LEU technology and irradiation techniques that have been successfully demonstrated, proven and implemented in several countries around the world and whose end products have obtained the approval of the Food and Drug Administration (FDA).

Our proposed MIPF will use technology that is in line with the very core of the ACT's mandated Lease and Take-Back program and will be able to produce significant quantities of Mo-99 via LEU irradiation techniques that have been proven successful and commercially scalable. To our knowledge, our company is the only party that has submitted a pre-application to the Nuclear Regulatory Commission (NRC) for technology that can make use of the DOE's Lease and Take-Back program for the production of Mo-99 in the United States. We have already engaged DOE to discuss the details of the Lease and Take-Back program which now addresses our fuel and disposal issues.

III. Proven Technology

As mentioned above, one of the key advantages of Coquí Radio Pharmaceuticals Corp. is that its proposed MIPF will have the capacity to produce a significant continuous domestic supply of Mo-99 for U.S. Citizens using proven fission based LEU/LEU technology.

The techniques that shall be employed by the company have been successfully demonstrated to reliably produce Mo-99 and have been proven and implemented in several countries around the world. For example, Australia's OPAL facility uses LEU fuel and LEU target plates and has demonstrated that high quality compliant Mo-99 can be reliably produced using traditional techniques based upon LEU. Australia has also demonstrated, from in-house economic analyses that have been independently verified, that it is possible to produce Mo-99 economically and to anticipate the full disposition of waste from Mo-99 production without significant increases in the price for Mo-99[2].

The LEU/LEU technology has also proven to be scalable. Initially built to supply Australia and small regional markets, following the Mo-99 supply crisis, OPAL capacity increased to 1000 Ci per week. On September 19, 2012 it was announced that Australia [3] will invest $168 million dollars into its existing OPAL reactor to make a Mo-99 radiochemical plant to further boost its production. The additional investment by the Australian government into LEU/LEU technology is a testament that the proposed technology for Coquí Radio Pharmaceuticals Corp. MIPF not only works but its model is economically viable.

Figure 1 – Schematic design of the 100,000 square feet Coquí Medical Isotope Production Facility.

IV. Technical Specifications

Coquí Radio Pharmaceuticals, Corp. will couple existing proven technology with tested designs to build its facility and will have the capability of supplying the U.S. market needs of Mo-99. The MIPF consists of twin, research-level, small nuclear reactors and radiochemical production lines. We shall take LEU targets and fission them in the research reactors, then the already fissioned target is taken to the processing cells and Mo-99 is extracted. Once the Molybdenum-99 is extracted, it will be delivered in the form of an aqueous solution, Sodium Molybdate, to our customers and they will distribute the end product to the hospitals.

Operations will be centered on a seven megawatt ("MW") nuclear reactor and Mo-99 processing facility. The research-level nuclear reactor consists of a small core of low-enriched, non-weapons grade uranium ("LEU") fuel and control rods suspended in an open pool of water. The water naturally circulates through the core to provide cooling for the reactor core and to slow down neutrons produced from the uranium fuel. The core follows strict safety standards and is protected by multiple redundant active (computer controlled) and passive (based on natural phenomena) safety systems that guarantee the safety of the facility and environment.

Mo-99 is produced by placing low-enriched uranium targets around the core to absorb neutrons. During this process, the uranium breaks into smaller elements including Molybdenum. Once a sufficient and cost-effective amount of Mo-99 has built up in the targets, they are removed from the core and cooled. The targets are then sent to the processing facility, where technicians use a chemical process to extract the Mo-99 and safely dispose of the by-products. The Mo-99 is purified using a second process and then condensed into the final product, Sodium Molybdate. Because the Mo-99 and target by-products are radioactive, all processing is performed in shielded labs, or "hot cells", with robotic manipulators. The industry-standard procedures are safe and efficient, allowing for more than 90% of the Molybdenum to be captured from the targets. The hot cells are arranged into several independent production lines, allowing for redundancy, simplified maintenance scheduling, and cost-effective expansion.

As part of the Lease and Take Back program in coordination with DOE, we will purchase/lease LEU Mo-99 targets. The targets are purchased pre-assembled as a uranium aluminum compound in metal casing. The casing facilitates both heat transfer to keep the targets cool during irradiation and prevents any by-products from contaminating the facility. As orders are received, targets will be loaded around the reactor core and irradiated for approximately five days. After irradiation, the targets are mechanically removed from the core and placed in a cooling tank. The targets are then transported to the processing facility via mechanical conveyor. In the first stage of processing, the targets are dissolved in a hot alkaline solution. Any gases produced from the dissolution step are trapped in containers and held until no longer an environmental concern, approximately four weeks. The resulting solution is then separated into the precipitate containing unused uranium and liquid containing Molybdenum. During the second stage, the Molybdenum liquid is passed through several exchange columns to extract purified Molybdenum and rinse out the majority of other by-products. All liquid and precipitate by-products are trapped in storage containers and set aside for disposal. Overall, the cooling and the purified Molybdenum, present as Sodium Molybdate, will be tested for radionuclidic and radiochemical purity according to the standards published by the British Pharmacopeia. Sodium Molybdate is a clear, almost colorless alkaline solution. The solution may contain up to 0.005% of its radioactivity from the following elements: Iodine-131, Ruthenium-103, and Tellurium-132. In addition, the solution may contain up to 0.00006% of radioactivity from Strontium-89 and Strontium-90, 0.0000001% from various alpha-emitting isotopes, and 0.01% from all other radioisotopes. Production batches of Mo-99 shall be tested for the above impurities using gamma-ray and alpha-ray spectrometry.

In addition, the radiochemical purity of Molybdenum in the form of Sodium Molybdate will be tested for each production batch using thin layer chromatography. The sum of Sodium Molybdate and Pertechnetate (the daughter of Mo-99 decay) radioactivity will be at least 95% of the total solution activity. Finally, the Sodium Molybdate will be assayed to determine the total amount of radioactivity, measured in units of six-day Curies. The solution will then be distributed and sold per six-day Curie.

During normal operation, each reactor will operate on a 28 day working cycle. Following each working cycle, the reactor will be shut down 2-3 days for preventative maintenance and refueling. In addition, a semiannual maintenance program will be scheduled to allow for component inspection, repair, and replacement. This schedule allows for an annual goal of 300 days of full-power reactor operation. With the exception of prolonged down time during semiannual maintenance, the target processing facilities will be operated up to seven days a week. At full capacity, the facility will be capable of generating up to 7,000 six-day Curies of Mo-99 per week.

With the exception of the Mo-99 targets, all chemicals and other consumables used during processing can be easily purchased from a chemistry laboratory supplier. The glassware and tubing used during processing is also conventional laboratory equipment. The alpha and gamma spectrometers can be purchased and repaired by any radiation equipment provider.

Although the gaseous by-products can be safely released after decay, the liquid and precipitate waste must be permanently disposed at a nuclear waste facility. The U.S. Department of Energy runs the Office of Civilian Radioactive Waste Management and we shall coordinate with them the transportation and disposal of radioactive waste as part of the Lease and Take Back program of the DOE. This should assist in the removal of waste from the facility to a nuclear waste disposal site in the continental United States. Regardless and/or while the DOE coordinates these efforts, waste will be stored on site following the best practices, standards and regulations for environmental and occupational safety.

The 100,000 square foot MIPF will be located in Alachua, Florida. The reactor hall, occupying approximately 30,000 sq. ft., is a multistory structure which holds the reactors core and auxiliary pool. The core will be submerged under approximately 10 m of water for safety. At its base, ports will extend through the concrete shielding to allow for research. Pneumatic tubes will move targets from the reactor core to the adjacent processing floor. The control rooms, also adjacent to the reactor hall, will allow the operators full view of the reactor and will be computer monitored. The processing floor will occupy approximately 30,000 sq. ft., and will house the concrete shielded hot cells, quality control labs, and supply storage. Shipping and receiving offices will be located adjacent to the production floor. The engineering rooms, approximately 5,000 sq. ft., will house all cooling equipment, including redundant centrifugal pumps and heat exchangers. The engineering rooms will also house the HVAC systems, which will have the ability to isolate the facility in the event of a radiation release. Monitors and carbon filters will ensure that the building is safe to the environment. The pumps will circulate the core water through the heat exchangers and water purification systems. Finally, 20,000 sq. ft. of office and administrative space and 2,500 sq. ft. of entry and security space will connect the primary areas.

Construction of the facility will be primarily concrete and steel. The building will be attached to local electricity, water, and sewer utilities, and will house redundant uninterrupted power generators to provide backup power to all reactor control systems for unplanned outages. The building is designed to meet all local and federal construction codes.

The economic impact of the construction phase of the project will generate in a non-recurring nature approximately 1,824 jobs, pay about $82.5 million in labor income into the local economy, create local total value added of about $113 million, and total output of $246 million into the local economy. The tax revenue impact is expected to be about $6 million to the state of Florida and $1.5 million to Alachua County over the construction and installation phase of the project.

The ongoing employment impact of the facility will be approximately 285 jobs in the local economy, approximate labor income of $14.4 million annually, total local value added of $17.6 million annually and total output of $31.2 million annually. Annual operations are expected to generate about $.78 million in sales and use tax revenue to Florida and as much as $.2 million to Alachua County.

V. Closing Statements

The driving philosophy of Coquí Radio Pharmaceuticals, Corp. is to assist in saving lives while operating a sustainable business model. Distributors of Technetium have been forced to ration supplies among and within countries, leaving hundreds of thousands of people without access to crucial diagnostic procedures; and it will only get worse.

The crisis is just beginning to be felt and hundreds of thousands of people have already been affected. The U.S. Citizens are and will be unable to get the critical pharmaceuticals they need to diagnose their ailments; procedures could be postponed and cancelled. In some cases, even a one day delay can make the difference between life and death.

The full force of the crisis is yet to be felt. Our Company believes something must be done quickly to implement a reliable, secure and continuous flow of a domestic significant supply of Mo-99 for the U.S. patient.

Sustainable Design + Proven Technology + Finance = Saving Lives + Global Threat Reduction (as a bonus added) **= A Better World.**

Mission Statement

Coquí will contribute to society by developing and operating the first U.S.A. dedicated Molybdenum-99 and radioisotope pharmaceutical production facility utilizing Low Enriched Uranium, thus:

- Providing a continuous source of Mo-99 for the world's nuclear medicine industry;
- Advancing Nuclear Medicine by establishing a state of the art production and research facility;
- Contributing to National Security by reducing the need for exports of weapon-grade uranium;
- Bringing much needed employment, new sources of industry and economic development.

References

[1] World Nuclear Association: www.world-nuclear.com: "Radioisotopes in Medicine" (updated: October, 2011)

[2] Australian Government, ANSTO: International Symposium on HEU Minimization "International Perspective on non-HEU Mo-99 Production" (23-25 January 2012)

[3] Australian Government: http://minister.innovation.gov.au/ "Australia leads the way with nuclear medicine initiative" (September 19, 2012)