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Waste Management Strategies for Production of Mo-99

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F.C. Johnson

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EXECUTIVE SUMMARY

Production of Mo-99 for medical isotope use is being investigated using dissolved low enriched uranium (LEU) fissioned using an accelerator driven process. With the production and separation of Mo-99, a low level waste stream will be generated. Since the production facility is a commercial endeavor, waste disposition paths normally available for federally generated radioactive waste may not be available. Disposal sites for commercially generated low level waste are available, and consideration to the waste acceptance criteria (WAC) of the disposal site should be integral in flowsheet development for the Mo-99 production. Pending implementation of the "Uranium Lease and Take-Back Program for Irradiation for Production of Molybdenum-99 for Medical Use" as directed by the American Medical Isotopes Production Act of 2012, there are limited options for disposing of the waste generated by the production of Mo-99 using an accelerator.

The commission of a trade study to assist in the determination of the most favorable balance of production throughput and waste management should be undertaken. The use of a waste broker during initial operations of a facility has several benefits that can offset the cost associated with using a subcontractor. As the facility matures, the development of in-house capabilities can be expanded to incrementally reduce the dependence on a subcontractor.

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LIST OF ABBREVIATIONS

AMIPA	American Medical Isotopes Production Act of 2012
ANL	Argonne National Laboratory
GTCC	Greater than Class C
LEU	Low enriched uranium
LLW	Low level radioactive waste
NNSA	DOE National Nuclear Security Administration
NRC	Nuclear Regulatory Commission
SER	Safety Evaluation Report
SRNL	Savannah River National Laboratory
TRU	Transuranic
TSV	Target solution vessel
ULTB	Uranium Lease and Take-Back Program for Irradiation for Production of Molybdenum-99 for Medical Use
UREX	Uranium Extraction
WAC	Waste acceptance criteria
WCS	Waste Control Specialists

1.0 Introduction

Technetium-99m (Tc-99m), the decay product of molybdenum-99 (Mo-99), is essential to nuclear medicine for diagnostic procedures, not only in the United States, but worldwide. Due to the relatively short half-life of Mo-99 (66 hours), it must be produced frequently in order to ensure continuous availability.[1] Mo-99 is not currently produced commercially in the United States and domestic use of Mo-99 relies on a highly interconnected and fragile global supply chain.[2] Due to previous shortages of Mo-99 in the United States and potential future shortages, the American Medical Isotopes Production Act of 2012 (AMIPA) was passed in 2013[3] in order to implement a technology-neutral program to support the production of significant quantities of Mo-99 for medical uses by a non-Federal entity without the use of highly enriched uranium.

Domestic production of Mo-99 via an accelerator driven process is currently being investigated using dissolved low enriched uranium (LEU).[4,5] LEU would be made available to Mo-99 producers as part of the Uranium Lease and Take-Back Program for Irradiation for Production of Molybdenum-99 for Medical Use (ULTB Program), which was established by the DOE National Nuclear Security Administration (NNSA) in February 2016 as directed by AMIPA.[6] With the production and separation of Mo-99, a low level radioactive waste stream (LLW) will be generated, which is sub-classified as Class A, Class B, Class C, or greater than Class C (GTCC) LLW.[7] Commercial disposal options are available for Class A, Class B, or Class C LLW;[6] however, there is currently no disposal path for commercially generated GTCC LLW (or GTCC-like waste)[8] or transuranic (TRU) waste. Until there is development of a disposal path for commercially generated TRU or GTCC waste, Mo-99 producers will be limited to producing waste that is Class C or below, which can limit operational flexibility. Constraints to the Mo-99 production process may require cleanup of target solutions on a more frequent basis to maintain TRU concentration below 100 nCi/g in the final waste form.[9] As a result, additional handling and processing of waste to maintain Class C or below can reduce the cost effectiveness of the facility.

The initial waste management strategy identified the individual waste streams anticipated for Mo-99 production (as shown below) and determined a path for each unique stream.[7]

- Target solution preparation and adjustment (Class A)
- Irradiation unit (Class A)
- Target Solution Vessel (TSV) Off-gas system (Class A and GTCC)
- Mo-99 extraction (class A)
- Mo-99 Purification (class A)
- Target Solution clean-up
    - Proprietary (class B)
    - Uranium Extraction (UREX) Raffinate (class B, maybe class C)
    - Thermal Denitration Evaporator Condensate (Class A)
    - Spent solvent replacement (class A)
    - Spent resin column (class C)
- Process vessel vent system (class A)
- Decontamination waste (class A)
- Coolant clean-up systems (class A)
- Radioactive liquid waste processing (GTCC)

Langton identified a baseline approach that describes the methodology required to perform the characterization, development, and qualification of an in-house waste treatment process.[10] The focus was on treatment and disposal of radioactive aqueous waste with a focus on cement-based waste forms. The

roadmap described by Langton was used as guidance for evaluating the waste streams associated with Mo-99 produced using an accelerator.

The intent of this document is to provide guidance on the constraints associated with the development of an in-house waste treatment strategy, as well as some background on offsite treatment options..

2.0 Waste Management Strategy

In Reference 7, the Nuclear Regulatory Commission (NRC) Safety Evaluation Report (SER) references a preliminary Mo-99 production facility design that includes a waste evaporation and solidification module. In 2014, Argonne National Laboratory (ANL) calculated that a Class C-compliant grouted waste form could be produced from the waste streams generated from Mo-99 production.[11] As part of this study, varying waste solution clean up cycles and separation processes were evaluated to remove Pu-239 (and Pu-241); Cs-137, and Sr-90. However, flowsheets involving separation of plutonium or cesium may result in TRU or GTCC orphan wastes that have limited or no disposal paths for commercially generated waste. Currently, the disposal facilities for commercially generated waste cannot accept TRU or greater GTCC wastes, which can limit operational flexibility in order to produce waste that is Class C or below. Separation of these components also may trigger other regulatory concerns. For example, to limit safeguards for the nuclear material facility, waste must meet the definition of attractiveness level E.[12] For a cementitious waste form, this concentration can be as high as 5 wt%, above which addition levels of accountability and security are required.

2.1 Waste Characterization and Classification

In a process facility that has several unit operations, each generating a waste stream, consideration must be given whether to combine or segregate dissimilar waste streams. The factors that would influence the outcome would be volume generated by each source and the regulatory classification of the individual and blended streams. When the process that generates a waste stream is under development (for example, optimization of the number of irradiation cycles between uranium cleanup operations), not only does the process efficiency need to be considered, but also the downstream effect on the classification of waste stream. The permutations of scenarios that can be identified in this type of situation are numerous.

2.2 Disposal Facility

Currently, there are four active, licensed low-level waste disposal facilities in the United States.

- Energy Solutions Barnwell Operations, Barnwell, South Carolina
  - Barnwell accepts waste from the states in the Atlantic compact (Connecticut, New Jersey, and South Carolina). Licensed by the State of South Carolina to dispose of Class A, B, and C waste.
- U.S. Ecology, Richland, Washington
  - Richland accepts waste from the Northwest and Rocky Mountain compacts. Licensed by the State of Washington to dispose of Class A, B, and C waste.
- Energy Solutions Clive Operations, Clive, Utah
  - Clive is licensed by the State of Utah for Class A waste only.
- Waste Control Specialists (WCS), LLC, Andrews, Texas
  - WCS accepts waste from the Texas Compact generators. Outside generators can seek permission from the Compact. Licensed by the State of Texas to dispose of Class A, B, and C waste.

2.3 Regulatory Considerations

AMIPA recognizes the need to provide commercial manufacturers of Mo-99 with a reasonable disposal path for waste. AMIPA asserts that DOE will retain responsibility for the final disposition of spent nuclear fuel created by the irradiation, processing, or purification of leased LEU and take title to and be responsible for the radioactive waste created by the irradiation, processing, or purification of leased LEU, for which the Secretary of Energy determines the producer does not have access to a disposal path. The

DOE NNSA has prepared a supplemental analysis for management of the LEU and associated waste generation in the production of Mo-99.[6] Whereas these programs have been outlined, the implementation may not be in place prior to the initial generation of waste.

2.4 In-House Treatment

Reference 10 details the design and analysis of a cementitious waste form. This methodology results in a front-loaded level of effort with planning and testing performed on simulated waste with the understanding that the process will have to be validated with actual waste streams once the facility is operational. The approach begins with characterization and classification of the waste stream(s), identifying the disposal facility, and finally, the design of the waste pretreatment and treatment with the purpose of achieving a final waste form that meets the disposal facility waste acceptance criteria.

2.5 Offsite Treatment

Alternatively, a simplified approach would be to engage a waste broker. A waste broker is a company that is licensed to transfer radioactive waste to licensed radioactive waste disposal or treatment facilities. Services can be as minimal as an interface between the waste generator and the disposal site, or as comprehensive as providing training and developing procedures at the waste generator. Table 2-1 summarizes some of the main differences between the use of in-house waste treatment and engaging services from a waste broker.

Table 2-1. Comparison of In-House Treatment Versus use of Waste Broker.

In-House Treatment	Waste Broker
Engage individual disposal facilities	Determine the appropriate disposal facility
Develop waste form	Characterize and develop waste treatment strategy
Dedicate facility/personnel to waste treatment	Perform waste treatment
Personnel for waste compliance/handling	Provide assistance with waste profiles/packaging
Dedicate facility for decay storage	Provides “hold for decay” service

A list of waste brokers and their services is located in Appendix A. In addition to the companies identified in the appendix, Perma-Fix Environmental Services has four facilities across the country that provide waste handling services including:

- Waste Handling Procedure Development
- Waste Minimization Plans
- Characterization
- Sampling and Analysis
- Treatability Studies
- On- and Off-Site Waste Repackaging
- Brokerage Services
- Profiling and Manifesting for Treatment or Direct Disposal
- Transportation Logistics Management
- Mixed Waste Treatment
- Large Components
- Thermal Destruction of Class A, B and C Resins

2.6 Trade Study

Conventionally, a trade study document would be generated evaluating the feasibility and cost of each of the strategies.[13] This approach would incorporate capital and operating costs into the assessment. A thorough study would also include an evaluation of the sensitivity of costs to the variability in operations. These variables would include the number of accelerators in operation, the cleanup schedule for purification of the target solutions and the value of maintaining separate waste streams or combining waste streams. An essential outcome of a trade study would be the generation of the information necessary to determine if waste treatment should be performed in-house, or by a subcontractor.

To pursue a trade study, there are several inputs that should be considered.

- Floor plan
  - In-house - Initial cost associated with a radioactive materials waste handling, treatment, and storage area, Operation, monitoring, and maintenance of the workspace is an ongoing expense.
  - Waste Broker – Smaller waste handling and storage footprint. Reduced equipment leads to reduced maintenance cost. Monitoring cost is similar; however contamination risk is reduced due to reduced handling.
- Characterization
  - In-house – Ongoing characterization for classification of waste encumbers analytical resources.
  - Waste Broker – Can provide sampling and characterization services as required when in-house capabilities are unavailable.
- Waste treatment
  - In-house – Development and demonstration of a waste treatment strategy. Includes capital cost for equipment, ongoing solidification materials costs, potential generation of additional waste streams generated by cleaning solidification equipment.
  - Waste Broker – Follows similar strategy as that described in Reference 10. Performs initial testing using simulants to demonstrate treatment of components that need treatment in addition to stabilization, if necessary. Confirms treatment/solidification with initial waste sample. Selects method for treatment/solidification to ensure waste form meets the waste acceptance criteria (WAC) of the disposal site.
- Waste handling – Comprised of packaging, preparation of manifests, and transportation management
  - In-house – Unless storage facilities are designed to hold sufficient waste for infrequent treatment and disposal, dedicated personnel are required to handle, track, and dispose of the waste stream or waste streams.
  - Waste Broker – Provides trained personnel with experience in waste handing. The use of experienced personnel can reduce risk associated with waste handling.
- Disposal site interface
  - In-house – Prior to initial shipments, the facility will be required to obtain certification by the disposal site in accordance with the sites quality assurance generator certification program.
  - Waste Broker – Many already have quality assurance approval from disposal sites. May file applications and proposed agreements on behalf of the waste generator.

3.0 Recommendations and Path Forward

Pending implementation of the ULTB, there are limited options for disposing of the waste generated by the production of Mo-99 using an accelerator. The commission of a trade study to assist in the determination of the most favorable balance of production throughput and waste management should be undertaken.

The use of a waste broker during initial operations of a facility has several benefits that can offset the cost associated with using a subcontractor. As the facility matures, the waste streams are better understood and the volumes generated are predictable. The development of in-house capabilities can be expanded to incrementally reduce the dependence on a subcontractor.

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Appendix A. Radioactive Waste Brokers -- Reproduced from Conference on Radiation Control Program Directors

Radioactive Waste Broker & Decontamination Services[1]

CRCPD Notes of July 12, 2016

Firm[2]	Served[3]	Contact	Voice Phone	E-mail	Mail out Leak Test Kit	Disassemble Devices	Decon/Remediate Bldgs & Grounds	Decon Vehicles	Deal with Radium Devices	Deal with Mixed Waste	Store for Decay	Assist with Import/ Export	Calibr Rad'n Meters	Provide Trng	Encapsulate as Spec Form	Has QA Approval from WCS
Ameriphysics	E & Mid-W	Chris Brandjes	TN 865/470-4176	cbrandjes@ameriphysics.com	Yes	some	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
Applied Health Physics	N.East	Anthony Hull	PA 412/835-9555	ahp.inc@comcast.net	Yes	some	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes		
Bionomics	E & Mid-W	John McCormick	TN 800/578-6513	bionomicsjohn@comcast.net	No	Some	Yes	No	Yes	Yes	No	No	No	Yes	Yes	Yes
Chase Environmental	All	John O'Neil	TN 865/816-6015	joneil@chaseenv.com	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	
Curie Environmental Services	All	Scott Logan	NM 505.888.9392	scott.logan@curieservices.com	no	some	some	yes	yes	yes	yes	yes	no	NORM	No	
DeNuke Services	All	Paul Jones	TN 865/813-1416	pjones@denuke.com	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	
Ecology Services	All	Paul Marshall	MD 800/932-7299	pmarshall@ecologyservices.com	Yes	some	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Energy Solutions (Duratek)	East	Donnie Brackett	TN 865/220-1526	dbrackett@energysolutions.com	No	Yes	Yes	Yes	No	Yes	Yes	Yes			Yes	Yes
		Danny Quayle	TN 865/425-4563	drquayle@energysolutions.com		Yes		Yes	Yes		No	yes	Yes	Yes		
Environ. Mgt. Ctrls. (EMC)	N.CA,NV,CO	Richard Gallego	CA 714-997-8090	rgallego@tgainc.com	Yes	No	Some	Yes	Yes	Yes	T½<120d	Yes	No	No	Yes	Yes
Environ. Mgt. Services	All	Thom Dias	CA 510/828-4962	diastd@sbcglobal.net	No	No	Yes	Yes	Yes	Yes	No	No	No	No		
New World Technol.	West	Mike Wilson	CA 925/443-7967	mike@newworld.org	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	
SECURE Energy Services	Mid-West	Kurt Rhea	CO 303-353-1979	krhea@secure-energy.com	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes		
NSSI	All	Robt. Gallagher	TX 713/641-0391	rdgallagher@nssihouston.com	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Philotechnics	All	Meghan Turvey	TN 865/285-3064	mgturvey@philotechnics.com	Yes	Yes	Yes	.	Yes	Yes	Yes	Yes	No	Some	Yes	Yes
		Robert Trimble	CA 858/586-2582	rstrimble@philotechnics.com	Yes	Yes	Yes									
Qal-Tek Associates	All	Travis Snowder	ID 888/523-5557	tsnow@qaltek.com	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Radiac Research	N-East	Art Green	NY 718/963-2233 x207	agreen@radiacenv.com	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No		Yes
Radiation Safety Assoc.	Atlantic	Paul Steinmeyer	CT 860/228-0487	kpstein@radpro.com	Yes	Yes	Yes	Yes	Some	Yes	No	Yes	Yes	Yes		
Radiation Solutions, LLC	All	Jon O'Rullian	ID 208-206-3203	jcorullian@radiationsolutionsonline.com	Yes	Yes	No	No	Yes	Yes	No	Yes	no	Yes	No	
RAM Services	All	Jerry Wiza	WI 920/686-3889	jwiza@ramservicesinc.com	Yes	Yes	Some	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes
R.M. Wester	Mid-West	Joe Koch	MO 636/928-9628	jkoch@rmwester.com	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes		
Rocky Mt. H.P. Consultants	Rocky Mts.	Edd Johnson	UT 801/560-3778	edsqared@aol.com	Yes	Yes	No	No	Yes	No	T½<120d	No	Yes	Yes	Yes	
RSO, Inc.	East	David Wellner	MD 301/953-2482 x306	dwellner@rsoinc.com	Yes	No	.	.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
		Greg Smith	MD 301/953-2482 x322	gdsmith@rsoinc.com	Yes	Yes	Yes									
Solutient Technologies	All	Dell Reuss	OH 330/497-5905	info@solutientech.com	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	Some		
Thomas Grey Assoc.	West	Richard Gallego	CA 714/997-8090	rich@tgainc.com	Yes	Some	Yes	Yes	Yes	Yes	T½<90d	No	No	Yes	Yes	Yes
Visionary Solutions,LLC	All	Anne Weaver	TN 865-482-8670	aweaver@vs-llc.com	No	No	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes
Waste Cont'l Specialists LLC	All	Lisa Berta	TX 432/525-8650	lberta@wcstexas.com	No	No	No	Some	Yes	Yes		Yes	No	No		Yes

1 All firms inspect materials, identify radionuclides, deal with leaking sources and associated contamination, provide packaging, contract for manufacturer's acceptance or waste processing and disposal as applicable, arrange transport and disposal permits, and report material transfer. Additional firms that specialize in NORM scale are on www.crcpd.org 'Free Documents,' 'Commercial Services,' see 'Radioactive Site Investigation and Decontamination Services.' Energy Solutions has a program for rental of radiation meters and other instruments. http://www.shopping.netsuite.com/Instrumentation

2 A firm is listed here if it has staff and equipment to provide the services, described in footnote 1 and columns, to the general public in multiple states and has good reputation among radiation control authorities.

3 Principal region served: North-East = north of Virginia, East = east of Mississippi River, Mid-west = from Rocky Mt. to Appalachians, West = west of great plains.

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