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Iraq Liquid Radioactive Waste Tanks Maintenance and Monitoring Program Plan

Matthew L. Dennis, Emad Sol Shamsaldin*, and John R. Cochran

* Iraq Ministry of Science and Technology, Radioactive Waste Treatment and Management Directorate

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Matthew L. Dennis and John R. Cochran
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0718

Emad Sol Shamsaldin
Iraq Ministry of Science and Technology
Radioactive Waste Treatment and Management Directorate

ABSTRACT

The purpose of this report is to develop a project management plan for maintaining and monitoring liquid radioactive waste tanks at Iraq's Al-Tuwaitha Nuclear Research Center. Based on information from several sources, the Al-Tuwaitha site has approximately 30 waste tanks that contain varying amounts of liquid or sludge radioactive waste. All of the tanks have been non-operational for over 20 years and most have limited characterization. The program plan embodied in this document provides guidance on conducting radiological surveys, posting radiation control areas and controlling access, performing tank hazard assessments to remove debris and gain access, and conducting routine tank inspections. This program plan provides general advice on how to sample and characterize tank contents, and how to prioritize tanks for soil sampling and borehole monitoring.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Dr. Abbas H. Zaboon, Radioactive Waste Treatment and Management Directorate (RWTMD) of Iraq's Ministry of Science and Technology (MoST), for providing current information and data on the state of the Al-Tuwaitha site. Dr. Zaboon is responsible for RWTMD's radioactive waste tanks maintenance and monitoring program. Additionally, thanks to David Kenagy from the U.S. Department of State for sponsoring this important work.

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ACRONYMS AND ABBREVIATIONS

COLIWASA	Composite Liquid Waste Sampler
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DOS	Department of State
EPA	Environmental Protection Agency
GOI	Government of Iraq
IAEA	International Atomic Energy Agency
LAMA	Active Metallurgical Testing Laboratory
MoENV	Iraq Ministry of Environment
MoST	Iraq Ministry of Science and Technology
NRC	Nuclear Regulatory Commission
QA	Quality Assurance
QC	Quality Control
RPC	Iraq Radiation Protection Center
RWP	Radiation work Permit
RWTMD	Radioactive Waste Treatment and Management Directorate
RWTS	Radioactive Waste Treatment Station
SNL (Sandia)	Sandia National Laboratories
TLD	Thermoluminescent Dosimeter

1.0 Introduction

The purpose of this document is to provide the Government of Iraq, specifically the Ministry of Science and Technology, with a program plan for maintaining and monitoring approximately 30 liquid radioactive waste tanks. While there are significant numbers of nuclear facilities and locations in Iraq, this report addresses only tanks at the Al-Tuwaitha Nuclear Research Center, located 18 km southeast of downtown Baghdad. Al-Tuwaitha (the area inside the security berm) covers more than a square kilometer and includes the remains of two research reactors, a fuel fabrication facility, plutonium separation facilities, and other support facilities. The Osiraq research reactor (or Tammuz) was bombed in 1981, and the remaining facilities were disabled or destroyed during Operation Desert Storm in 1991.

In 2003 following Operation Iraqi Freedom, looters scavenged material from Al-Tuwaitha. There are other sites in the country that are contaminated and will require decommissioning and remediation to ensure radiological safety. Because of past military operations, lack of upkeep, and looting, there is now a safety and radioactive waste problem within the Al-Tuwaitha central nuclear complex and other locations which contain various

- uncharacterized radioactive wastes,
- **uncharacterized liquid radioactive waste in underground tanks,**
- wastes related to the production of yellow cake,
- sealed radioactive sources,
- activated metals, and
- contaminated metals.

This report focuses on the liquid radioactive waste tanks. Of the approximately 30 tanks that contain or did contain liquid radioactive waste, more than half were not intended to be long-term “storage” tanks for radioactive waste. Most, in fact, were process vessels used in fuel dissolution, radioactive waste treatment, or radioisotope production. There is no inventory of the contents or former contents of any of these tanks. Therefore, concern

exists about these tanks, and an appropriate maintenance and monitoring program needs to be developed to ensure these tanks are retaining the potential contaminants and not endangering worker or public health and safety. The plan presented in this document was written to meet the needs of Iraq's maintenance and monitoring program for Al-Tuwaitha; it addresses tank inventory, contamination mitigation, routine maintenance and monitoring for leak containment, radiological posting, and tank access procedures.

Iraq's Ministry of Science and Technology (MoST) owns the nuclear facilities at Al-Tuwaitha and is responsible for characterization, cleanup, and waste management. Sandia National Laboratories (Sandia) is providing support for MoST's Radioactive Waste Treatment and Management Directorate (RWTMD), which is responsible for the liquid radioactive waste tanks. This report will formulate a liquid radioactive waste tank maintenance program and address the following challenges in assessing the liquid radioactive waste tanks:

1. Develop a tank maintenance and monitoring program.
2. Suggest methods for tank content characterization (Appendix D).
3. Suggest methods for soil monitoring.

This work is funded by the U.S. Department of State (DOS) and supports the Iraq Nuclear Facility Dismantlement and Disposal Program (Iraq NDs Program). The Iraq NDs Program provides expert advice, training, and limited equipment to Iraq, so the Government of Iraq (GOI) can remediate its radioactively contaminated facilities and safely dispose of its radioactive wastes. The program is organized in association with the International Atomic Energy Agency (IAEA) and has participation of several countries (see http://www-ns.iaea.org/projects/iraq/). The DOS is coordinating the U.S. government assistance from Sandia, the U.S. Department of Energy (DOE), Texas Tech University, the U.S. Environmental Protection Agency (EPA), the U.S. Nuclear Regulatory Commission (NRC), and others.

Report Layout

The liquid radioactive waste tank maintenance program addressed in this report highlights the following:

- **Chapter 2, Known Tank Inventory:** Presents an inventory of all known liquid radioactive waste tanks at Al-Tuwaitha. This inventory, assimilated from personal conversations with MoST employees, information from a former IAEA inspector, and current tank inspections provides a comprehensive listing of known waste tanks and their present situation.
- **Chapter 3, Safe Access to Tanks:** Provides suggested procedures for accessing the radioactive waste tanks. Because a major portion of the monitoring and maintenance plan will require visual inspection, access to the tanks must be readily available. This is complicated because the facility was bombed two decades ago. Therefore, the initial inspection may have to be proceeded by hazard assessment, debris removal, and site preparation.
- **Chapter 4, Post and Control:** Documents how tanks that pose a radiological hazard must be posted as such to limit exposure once obstacles to those tanks are removed. Additionally, any measures that can limit the spread of radioactive contamination need to be implemented.
- **Chapter 5, Maintain and Monitor:** Describes routine maintenance, monitoring, and leak containment. For the foreseeable future, GOI does not have the capacity to dispose of radioactive material. Once the tank sites are all accessed, the waste and (if needed) the surrounding environment can be characterized. Once appropriate controls are enacted to maintain the tanks in a standby condition, the GOI can consider their alternatives to ultimate disposal and dismantlement of the tanks.
- **Chapter 6, Soil and Groundwater Investigation:** Develop a plan for soil boring locations within Al-Tuwaitha. Soil samples from high priority tank locations, such as those with in-ground piping and no secondary containment, can be analyzed to determine subsurface contamination. Subsequently, the soil boreholes can be used for long-term contaminant migration monitoring in conjunction with a groundwater monitoring program (see *Groundwater*

Monitoring Program Plan for the Al-Tuwaitha Nuclear Research Center (Copland, 2011)).

- **Appendix A:** Presents a 2007 IAEA overview from R. Coates and G. Healey on the status of nuclear facilities at Al-Tuwaitha. The document presented here gives a description of all facilities at Al-Tuwaitha, but only locations with liquid radioactive tanks were utilized for Appendix B.
- **Appendix B:** Presents the database of information about the liquid radioactive waste tanks at the Al-Tuwaitha Nuclear Research Center. This database presents tank characteristics for 30 tanks at 9 different sites within Al-Tuwaitha.
- **Appendix C:** Describes radioanalytical methods and associated equipment for ex-situ analysis. Since the Radiation Protection Center (RPC) and MoST have limited radiation detection equipment, additional equipment and potential off-site laboratory testing is recommended here to fully characterize tank radioactive constituents.
- **Appendix D:** Describes determining external tank contamination and obtaining internal samples. Prior to personnel obtaining internal samples for ex-situ radiological examination, the radiation hazards surrounding the tanks need to be analyzed. Additionally, a characterization plan will develop data used for decision on future decontamination and decommissioning activities involving liquid radioactive waste tanks.

2.0 Liquid Radioactive Waste Tank Inventory

This section presents known information on the inventory of tanks and their contents. In early-2010, Sandia hosted representatives from MoST's Radioactive Waste Treatment and Management Directorate (RWTMD) in Albuquerque, NM. A summary of what was accomplished is provided below for historical documentation.

- Met with Iraqi representatives (Dr. Emad Sol Shamsaldin, Amir Mossa Jabr, and Mazin S. Atta Al-Janabi) from MoST on February 25, 2010, to discuss the liquid radioactive waste tank maintenance program. Through discussions, determined that most tanks have secondary containment in basements or vault-like rooms. Visual leak inspection with appropriate radiation safety controls becomes the most likely monitoring technique.
- Determined MoST lead person for cooperation with Sandia would be Dr. Emad Sol Shamsaldin.
- MoST provided engineering drawings for eight potential liquid radioactive waste tanks. Electronic and photo copies were made and provided to Sandia and MoST.
- Compiled a draft spreadsheet of all liquid radioactive waste tanks at Al-Tuwaitha. This includes information on tank capacity, estimated actual quantity, source of contents, location, suspected radioactive and chemical constituents, estimated/measured activity, etc.

There is virtually no engineering documentation for the facilities at Al-Tuwaitha. During the MoST visit to Sandia, eight engineering drawings were provided for French-supplied process tanks. However, it was determined that none of these engineering drawings matched with known liquid radioactive waste tanks.

The lack of engineering drawings and, most importantly, the lack of process inventory data which would indicate what chemicals and radionuclides exist in the tanks make planning for tank maintenance and monitoring difficult. The first step is to determine the spatial orientation of the approximately 30 tanks divided amongst the nine sites at Al-Tuwaitha.

2.1 Al-Tuwaitha Nuclear Research Center

The 1.3 km^2 Al-Tuwaitha Nuclear Research Center is situated approximately 1 km east of the Tigris River. The facility is fortified by large earthen berms and is situated 18 km south of Baghdad. Figure 1 shows an aerial satellite view of Al-Tuwaitha outlined in yellow.

Figure 1. Aerial satellite view of Al-Tuwaitha Nuclear Research Center with the Tigris River to the west and Baghdad to the north

The nuclear research facilities at Al-Tuwaitha were built by various nations during the development of Iraq's nuclear research center. Therefore, the area inside the earthen berm is divided into sectors. The French, Italian, and Russian sectors are so named because those were the nations that designed and built the nuclear research facilities in those sectors. Figure 2 depicts the building layouts within Al-Tuwaitha and the associated sector names.

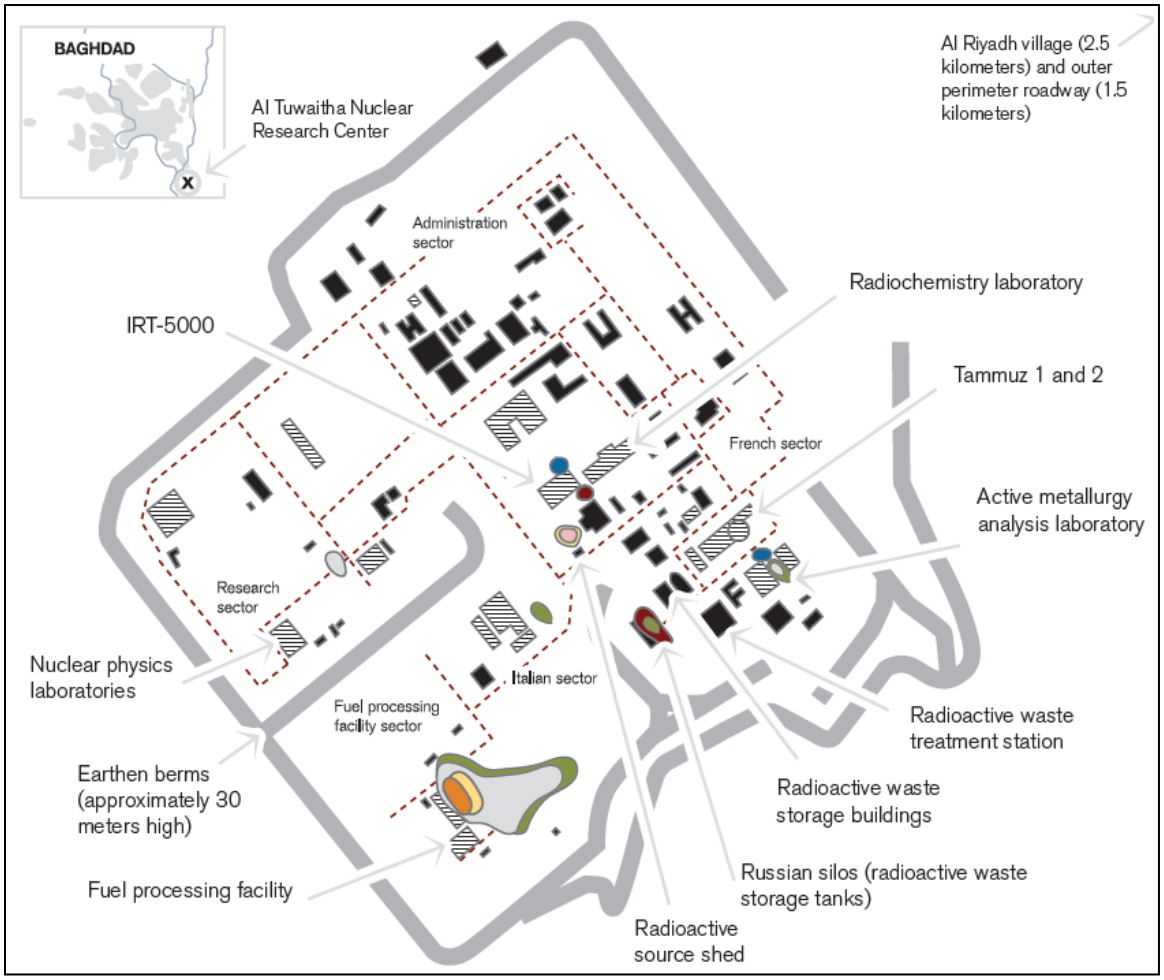

Figure 2. Facility locations within Al-Tuwaitha (Chesser, 2009)

2.2 Individual Tank Characteristics

Not all locations in Figure 2 have tanks with liquid radioactive waste. The suspected locations with liquid bearing tanks are associated with nine facilities:

1. Radioactive Waste Treatment Station (RWTS)
2. Russian Radioisotope Production
3. IRT-5000 Reactor
4. Tammuz-2 Reactor
5. Fuel Fabrication Building
6. Russian Silos
7. Active Metallurgical Testing Laboratory (LAMA)

8. Italian Radioisotope Production
9. Radiochemistry Laboratory

These locations and corresponding number are depicted in Figure 3

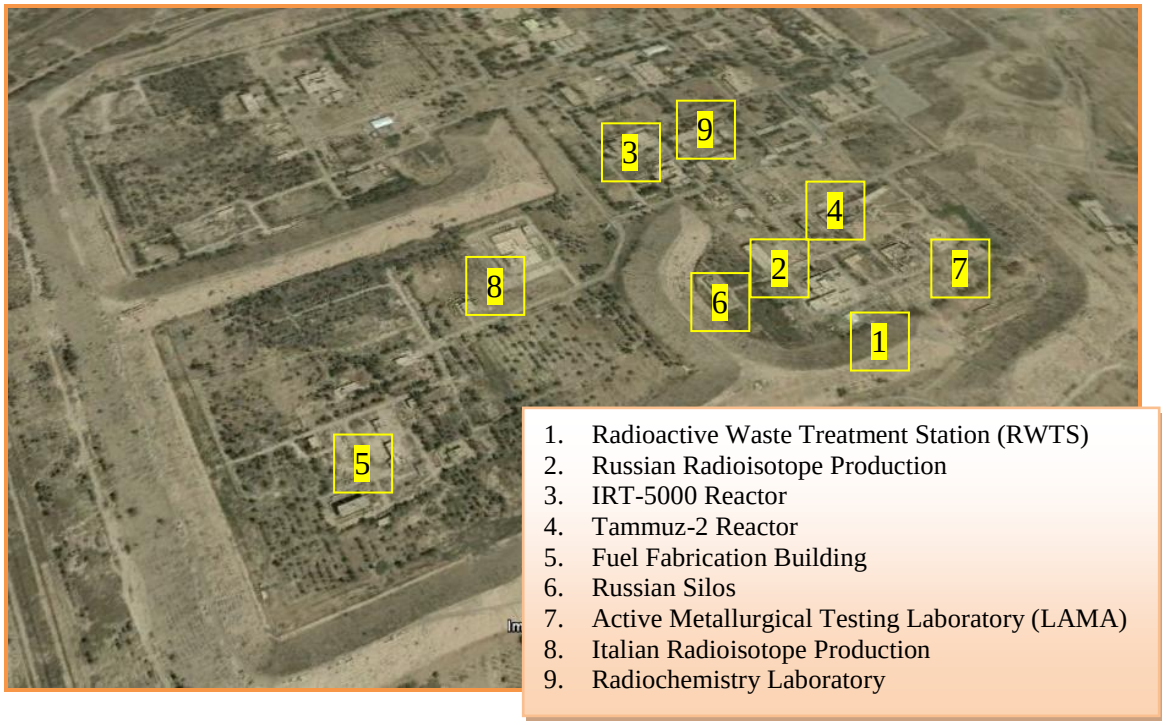

Figure 3. Aerial satellite view of Al-Tuwaitha Nuclear Research Center with liquid radioactive waste tank locations. Image courtesy Google Maps.

In order to piece together the conflicting liquid radioactive waste tank accounts from IAEA inspector accounts, personal on-the-ground recollections from MoST personnel, and international PowerPoint presentations, Sandia developed a spreadsheet database to track all tanks within the Al-Tuwaitha Nuclear Research Center (Appendix B). The initial information for this database came from a former IAEA inspector and is documented in the "Status of Nuclear Facilities at Al-Tuwaitha" recounted by R. Coates and written by G. Healey. This document, which can be found in Appendix A, lists 18 sites at Al-Tuwaitha where nuclear research activities occurred (Cochran, 2009). Based

on this list, sites containing liquid radioactive waste tanks were identified and compared against Figure 4, an excerpt from a 2008 IAEA presentation by MoST's M. Rasheed.

Facility	Capacity of tanks m^3	Quantity of liquid m^3	Generated	Activity/Radionuclide
RWTS	10	About 10	decontamination	MLW Co^{60}, Cs^{137}
	5	About 2	Laundry	LLW Co^{60}, Cs^{137}
	3	Less than one	concentration	HLW Co^{60}, Cs^{137}
	2 tanks underground	7	Drainage	MLW Co^{60}, Cs^{137}
Radiochemistry	10	5	Processing of nuclear fuel	HLW fission products and actinides
IRT-5000	2 X100 well storage	Little	Work activity	LLW Co^{60}, Cs^{137}
Tammuz-2	One (-4 level)	About one	Work activity	LLW Co^{60}, Cs^{137}

Figure 4. M. Rasheed 2008 IAEA Presentation on Liquid Radioactive Waste Tank Characteristics

Using the information from G. Healey and M. Rasheed, Sandia assembled an initial liquid radioactive waste tank database for tanks at the nine locations discussed previously. The database contains the following information for each individual liquid radioactive waste tank; however, there is not a complete history of every tank:

1. Tank Name
2. Picture
3. Tank Facility Location (RWTS, LAMA, etc.)
4. Building Number (see Appendix A)
5. Tank Construction Material
6. Engineering Drawings Available (Yes/No)

7. Disposition (Reuse or Scrap)
8. Connected Underground Piping (Yes/No)
9. Secondary Confinement (Type or None)
10. Accessibility Description
11. Rated Capacity (m^3)
12. Estimated Quantity Remaining (m^3)
13. Percentage Liquid
14. Percentage Solids/Sludge/etc.
15. Material Origin
16. Waste Class
17. Radionuclides
18. Activity Concentration (Bq/ml)
19. Activity Concentration (Ci/m^3)
20. Dose Rate (μSv/hr)
21. Notes

In mid-2010, Sandia received new data from a presentation by A.H. Zaboon from MoST with the addition of dose rate data. Figure 5 shows updated tank characteristics from A.H. Zaboon's PowerPoint presentation.

Facility	Qua	Material	Capacity of tanks m³	V0lume of liquid m³	Generated	Activity/Radionuclide
Fuel fabrication	2	St. Steel	3	sludge	Fuel fabrication	Natural U
	1	Concrete	_	sludge	_	_
RWTS	1	St. Steel	10	~ 10	Treatment of radiochemistry waste	MLW ^{60}Co, ^{137}Cs + Fission products
	1	St. Steel	5	~ 2	Laundry	LLW ^{60}Co, ^{137}Cs + Fission products
	1	St. Steel	3	Less than one	concentration	HLW ^{60}Co, ^{137}Cs + Fission products
	2	St. Steel	2, 5	7	Drainage	MLW ^{60}Co, ^{137}Cs
Radiochemistry	1	St. Steel	10	5	Processing of spent fuel	HLW fission products and actinides
IRT-5000	2	Concrete	100	sluge	Reactor primary circuit	LLW ^{60}Co, ^{137}Cs
Tammuz-2	1	St. Steel	-	About 1 m3	Reactor primary circuit	LLW ^{60}Co, ^{137}Cs
Radioisotopes	2	Concrete	100	sludge	—	--
	4	St. Steel		sludge	—	LLW ^{60}Co
Russian silo	2	Concrete	—	sludge	—	—
LAMA	1	St. Steel	—	—	—	Traces of tritium

Figure 5. A.H. Zaboon 2010 IAEA Presentation on Liquid Radioactive Waste Tank Characteristics

In June 2010, A.H. Zaboon provided additional pictures and information to populate the database. Currently, Sandia has accumulated partial data on 30 individual radioactive waste tanks at Al-Tuwaitha, of which 13 are classified as having no secondary containment (such as location within a basement) or as containing a substantial percentage of liquid waste. These two categories of tanks are listed below with their formal names (i.e., locations), the Sandia-Iraq generated abbreviations, and the type of secondary containment or percentage of liquid:

1. No Secondary Containment
    - 1.1. Russian Radioisotope Production, RR3, concrete tank
    - 1.2. Russian Radioisotope Production, RR4, concrete tank
    - 1.3. IRT-5000 Reactor, IR1, concrete tank
    - 1.4. IRT-5000 Reactor, IR2, concrete tank
    - 1.5. Fuel Fabrication, FF1, concrete pit

1.6. Russian Silos, RS1, concrete tank

1.7. Russian Silos, RS2, concrete tank

2. Majority Liquid Contaminant

2.1. Radioactive Waste Treatment Station, RW4, 100% liquid

2.2. Radioactive Waste Treatment Station, RW5, 30% liquid

2.3. Radioactive Waste Treatment Station, RW8, 100% liquid

2.4. Radioactive Waste Treatment Station, RW9, 100% liquid

2.5. Tammuz-2 Reactor, TA1, 20% liquid

2.6. Radiochemistry Laboratory, RL, 50% liquid

The complete liquid radioactive waste tank database can be found in Appendix B. It should be noted that data collected from Figure 4 and Figure 5, information from MoST personnel, and IAEA inspector accounts are not in agreement. However, the database in Appendix B makes the best attempt to assimilate and corroborate data from the various sources and explicitly highlights where data is suspect or missing.

3.0 Procedures for Initially Accessing Radioactive Waste Tanks

The purpose of this section is to assist MoST in developing an initial hazard assessment for each tank location, construct a work plan for debris removal and site preparation, and assess tank integrity. Because a major portion of the maintenance and monitoring plan will require visual inspection and dose measurements, access to the tanks must be readily available. This is complicated due to facility disrepair due to bombing. This section discusses radiation standards that could be applied to the anticipated radiological work. Further, this section addresses work planning and controls for accessing a radiological area, hazard analysis considerations for debris removal and site preparation, and ultimately determining tank integrity.

3.1 Radiological Standards

Most international and country specific regulations pertaining to radiation protection are directly derived from the recommendations of the International Commission on

Radiological Protection (ICRP) Publication 60 (ICRP, 1990). The general considerations for radiation protection are as follows:

1. No person should be exposed to man-made radiation unless some benefit is derived from the exposure. In our case, the intent is met by preventing further radioactive contamination of the Al-Tuwaitha site and providing long-term stewardship and remediation of the facilities.
2. Radiation exposure limits are set at such levels that non-stochastic biologic effects do not occur. To that end, the guidance in this document follows internationally accepted radiation exposure limits.
3. Radiation exposure limits are set at such levels that stochastic effects are minimized and acceptable in light of the benefits. Again, the guidance in this document follows internationally accepted radiation exposure limits.
4. In all proposed activities, those conducting radiological work are responsible for adhering to the internationally accepted notion of keeping radiation exposure as low as reasonably achievable (ALARA). All work planning and controls should consider this premise before, during, and after completion of any project.

In order to limit the risk to personnel accessing liquid radioactive waste tank locations, the occupational exposure of any worker shall be controlled so that the following limits are not exceeded (IAEA, 1999, RS-G-1.1):

(a) An effective dose of 20 mSv per year averaged over five consecutive years;
(b) An effective dose of 50 mSv in any single year;
(c) An equivalent dose to the lens of the eye of 150 mSv in a year; and
(d) An equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

Exposure of the personnel to external radiation may be controlled by concurrent application of one or more of the following three standards (IAEA, 2008):

1. **Minimizing exposure time:** overexposure can be prevented through restricting of exposure time so that the product of dose rate and exposure time does not exceed the maximum allowable;
2. **Maximizing distance from the radiation source:** radiation exposure decreases with increasing distance from a radiation source (distance is the most easily applied principle of radiation protection);
3. **Shielding the radiation source:** shielding is accomplished by placing some absorbing material (such as concrete, lead, etc.) between the source and the person that is to be protected.

Further limitations or administrative controls will need to be developed in separate documentation from the RPC.

3.2 Tank Location Hazard Assessment

The radiological and physical status of locations listed in Section 2.1 must be determined or "characterized." Characterization may be described simply as the gathering of data, facts, and information necessary to identify situations that may arise during the dismantling of a facility and that may affect workers, the public, or the environment. Broadly, it comprises the following:

1. Analysis of structural conditions of the facility that may affect the safety or protection of workers.
2. Determination of the extent, nature and concentration of radioactive contamination and conventional chemical contaminants.
3. Preparation of an inventory of situations that might be hazardous to workers, the public or to the environment.

For physical characterization, MoST will need to need to inspect each radioactive waste tank location to detect hazards and identify the arrangements required for protection against any abnormal radiological or conventional conditions. The purpose of such an examination is to document the current state of the facility through photographs, videos,

maps, and diagrams that may help determine what hazards are present. The product of this hazard assessment should develop information used in the work planning and controls evaluation. The following information needs to be cataloged for each facility where a liquid radioactive waste tank resides (IAEA, 2008):

1. The condition of the framing, floors, walls, structural stability of damaged buildings, and to assess the possibility of an unplanned collapse of any unsafe portion of the structure;
2. The need to brace the walls and floors of structures which have been damaged and which employees must enter;
3. What rubble, scrap, or structurally unsound material can be safely removed to access the tank location;
4. The types of hazardous chemicals, gases, explosives, and flammable materials that have been used in any pipes, tanks, or other equipment on the property;
5. Confined space requirements;
6. Control systems (security entrances, fencing, etc.);
7. Fire protection (detectors, alarms, fire-fighting systems, etc.);
8. Radiation protection systems (adequacy, functionality, and efficiency);
9. Issues for staff safety (physical hazards, hazardous materials, etc.);
10. Functionality of systems (heating, ventilation, air and electricity supply, internal and external lighting, etc.); and
11. Process materials (in containers or tanks, contaminated site areas, etc.).

An integral and complimentary part of the liquid radioactive waste tank inventory characterization is the radiological hazard characterization. To date, minimal dosimetric data exists for all tanks, especially those tanks that pose significant access challenges. Therefore, for radiological characterization, MoST should perform preliminary radiological characterization involving identification of the radiological hazards to which the workers might be exposed. This hazard identification helps to determine whether or not it is necessary to decontaminate any areas of the facility for direct worker access, and it facilitates the design of suitable radiological protection measures for later activities.

The activity and location of the radioactive sources at the facility are considered, together with any additional hazards arising from activities or processes, and initiating events that create the potential for causing harmful consequences for workers, the public, or the environment are identified (IAEA, 2008). As a minimal first step, the radiological worker accessing the tank locations needs to be provided with:

1. Portable radiation survey instruments (Geiger-Mueller or Portable Ion Chamber discussed further in Appendix C);
2. Personnel-monitoring dosimeters (TLD or Electronic Personal Dosimeter); and
3. Swipes or sample containers for analysis of removable contamination

Procedures for radiological surveys, including removable contamination levels, are discussed in Appendix D and will need to be reiterated as work is completed so an up-to-date radiological survey is maintained for the work area.

3.3 Work Planning and Controls

When an operation is to be conducted during which significant radiation or contamination levels may be encountered, or implementation of which may be complex (involving several working groups and numerous activities), advance work planning is one of the most important means of achieving optimization of protection. A Radiation Protection Officer from the RPC should take part in the planning of activities involving significant exposures, and should advise on the conditions under which work can be undertaken in controlled areas.

MoST will need to develop written procedures as part of the work process to access the liquid radioactive waste tank locations. Elements to be considered include:

1. Information from similar work completed previously (i.e., lessons learned and equipment utilized in decommissioning and demolition of the LAMA facility);
2. Time for starting the work, its estimated duration, and the human resources involved;

3. Maps of estimated dose rates;
4. Other activities in the same area that may interfere with the work;
5. Preparation and assistance in operations (isolation of the process, scaffolding, insulation work, etc.);
6. Protective clothing and tools to be used;
7. Communication necessary to ensure supervisory control and coordination;
8. Handling of waste arising;
9. Removal or shielding sources of radiation;
10. Plan access and exit from the work area;
11. Provide for service lines (i.e., air, welding, ventilation, electrical, etc.)
12. Pre-plan activities so that only the necessary equipment and tools are introduced into potentially contaminated areas;
13. Provide communication between supervisors and radiological workers for emergencies and unanticipated occurrences.

In some countries, the radiological precautions to be taken would be documented in a Radiation Work Permit (RWP). The RWP is issued by the persons in charge of the planning of the operations in collaboration with the Radiation Protection Officer. A copy of the RWP would be provided to the supervisor of the work and should remain with the working team during the performance of the work. In addition to a description of the work to be performed, the RWP may include:

1. Identification of "confined space" safety hazards for work in basements, crawl spaces, or limited access areas consider;
2. A detailed dose rate map of the working area and possible hot spots, produced from a survey made prior to the work or otherwise estimated;
3. An estimate of contamination levels and how they may change during the course of the work;
4. An estimate of individual and collective exposure for each work step;
5. Specification of any additional dosimeters to be used by the workers;
6. Specification of protective equipment to be used in different phases of the work;

7. Details of any time or dose restrictions;
8. Instructions on when to contact the Radiation Protection Officer.

3.4 Debris Removal and Site Preparation

After developing a Radiation Work Permit (or equivalent) and technical work planning documentation, MoST can consider procedures to access the most troublesome tanks in locations where workers were not previously able to enter readily.

Site preparation for the facilities with currently inaccessible liquid radioactive waste tanks can be performed safely provided that all of the following health tips and precautions are met (IAEA, 2008):

- The hazards of the materials are known and appropriate precautions can be taken to prevent excessive personal exposure.
- Precautions have been taken to ensure no further liquid is released to the environment.
- The cleanup procedures are known and the proper equipment (e.g., personal protective equipment (PPE) and spill cleanup materials) are available.
- A first aid kit must be available to disinfect any cuts or abrasions (protect open cuts and abrasions with waterproof gloves or dressings). Proper equipment for prompt transportation of an injured worker, as well as a communication system to contact any necessary ambulance service, must be available at the job site. In the absence of an infirmary, clinic, hospital, or physician that is reasonably accessible in terms of time and distance to the worksite, a person who has a valid certificate in first aid training should be available at the worksite to render first aid.
- Plenty of drinking water must be available when working in hot environments. Heat stress can be reduced using sunscreen, taking frequent rest breaks, and wearing light-colored, loose-fitting clothing.
- Trenches, excavations, and gullies must be supported or their stability verified prior to worker entry.

- Any obvious hazards (downed power lines, frayed electric wires, gas leaks or snakes) must be reported to appropriate authorities.
- Fuel-powered electrical generators must be operated outdoors as they may pose a carbon monoxide (CO) hazard.
- All internal combustion equipment (such as electrical generators) should be shut down prior to refueling. Fuel for this equipment should be stored in a safe location.
- Sufficient firefighting equipment should be located near any flammable or combustible liquid storage area. A temporary or permanent water supply of sufficient volume, duration, and pressure required to properly operate the firefighting equipment should be made available. Smoking should be prohibited at or in the vicinity of hazardous operations or materials.
- Use extreme caution when handling containers holding unknown substances or known toxic substance.
- Prevent touching downed power lines or any object or water that is in contact with such lines.
- If possible, all workers involved in the various phases of remediation of a contaminated site should be appropriately trained, with the workers certified in both radiological and non-radiological hazardous worker safety.
- Demolition of exterior walls and floors must begin at the top of the structure and proceed downward. Structural or load-supporting members on any floor must not be cut or removed until all stories above such a floor have been removed. Masonry walls must not be permitted to fall on the floors of a building in masses that would exceed the safe carrying capacities of the floors.
- No wall section one story in height or higher shall be permitted to stand alone without lateral bracing unless such a wall was originally designed and constructed to stand without such lateral support and is safe enough to be self-supporting.
- All walls must be left in a stable condition at the end of each work shift. Employees shall not work on the top of a wall when weather conditions create a hazard.

- Only workers necessary to perform decontamination and demolition operations may be permitted in the work area at any time. No unauthorized entry should be permitted to the area during demolition.
- Special attention should be paid to weather conditions. No work should be done during inclement weather, such as during lightning or high wind situations. The worksite should be wetted down, as needed, to control dust. Fixatives can eliminate potential exposure to airborne contamination.

Once the facility location is prepared for entry through demolition activities, personnel can consider entering the facility. Based upon the hazard and risk assessment for the facility, determinations will be made on the safety for entry to conduct radiological surveys and tank integrity assessment.

3.5 Tank Integrity Assessment

Assuming the facility is prepared for access and all major obstacles are removed to provide appropriate workspace for tank inspection, personnel will need to ascertain the tank integrity through visual inspection. Visual inspection provides the first indication of tank integrity and confirms prioritization of the 13 tanks identified in Section 2. Additionally, visual inspection provides an initial assessment on whether a tank contains radioactive waste and, in many cases, the only valid avenue of non-destructively assessing the integrity.

3.5.1 External Visual Inspection

For an initial assessment, once physical access to the tank is granted, external visual inspection of the tank will provide the first indication whether or not a tank has leaked. Many of the suspect tanks at Al-Tuwaitha have secondary containment (such as a basement or pit). However, as described in Section 2, thirteen tanks are thought to have no secondary containment or contain substantial liquid radioactive waste, and others may be connected to pipes that enter the soil. Consequently, these tanks will be the first

candidates for immediate integrity assessment. The overall process for determining tank integrity is as follows:

1. Visual inspection of the tank surroundings:
    a. Is liquid present?
    b. Is there staining to indicate past leakage?
    c. Do radiation measurements indicate past leakage?
    d. Are shutoff valves, pumps, or piping missing, disabled, or inoperable?
    e. Are concrete surfaces coated to reduce contaminate wicking and reduce decontamination efforts?
    f. Does the secondary confinement area contain drains to other locations?
    g. Most tanks are assumed to be stainless steel construction. Is there any material degradation or corrosion noted on the vessel?
    h. Do any of the tanks include instrumentation probes such as tank level, temperature, etc.? Note the condition of this instrumentation and the functionality.

The personnel conducting the visual inspection of the tank need to record the following information in order to further characterize the tanks:

1. Provide a schematic of the physical location of the tank within the facility, and subsequently provide a schematic of the tank spatially within its unit. This provides supplementary information necessary due to the lack of engineering drawings.
2. Provide a description of co-located equipment such as other tanks, pumps, valves, piping, etc.
3. If the tank is located in a basement or pit, determine whether there is any standing liquid, sludge, or dried material nearby. If the tank is located above grade or outdoors, indicate if there is any suspicious material around the tank.

4. Indicate where piping, including ventilation lines, enters or leaves the tank and where it is connected. Conversely, indicating where piping, pumps, or valves are missing, inoperable or damaged is equally important.
5. Further inspection in or around the tank should not proceed until the appropriate radiation protection entity determines it is safe.
6. Remove scrap or damaged equipment or piping preventing access to the tanks. Material should only be removed after it is cleared based on a radiological survey.

3.5.2 Internal Visual Inspection

Once external visual inspections have been completed, more complicated internal tank inspection could occur. However, internal visual inspection of tanks introduces the potential for radioactive contamination of sampling or inspection equipment and personnel. When considering whether to open tanks that contain a potentially significant quantity of radioactivity and removable contamination, refer to Appendix D, which discusses general guidelines for sampling or inspecting tank contents. Thus, Appendix D should be utilized in conjunction with radiation protection guidelines presented below in Section 4.0.

4.0 Mitigation Actions

The purpose of this section is to advise MoST on how to implement posting and access controls for tank locations and segregate tanks in order to prevent environmental contamination. Once obstacles to a tank are removed, the tanks that pose a radiological hazard should be posted as such to limit exposure. Additionally, any measures that can limit spreading radioactive contamination need to be implemented.

4.1 Postings and Access Controls

In the United States, radiation area postings can generally be divided into six types: radiation area, high radiation area, very high radiation area, contamination area, high contamination area, and airborne radioactivity area. The level of training and required

safety equipment generally increases from radiation area to airborne radioactive area. The level of posting is commensurate with the results of the radiological survey and the limits described for each type of area.

Radiological posting requirements based on U.S. guidance include the following (DOE, 2008):

1. Radiological postings are intended to alert individuals to the presence of radiation and radioactive materials and to aid them in controlling exposures and preventing the spread of contamination. Boundaries should be used to control access and movement of material to ensure safety.
2. Signs shall contain the standard radiation symbol (radiation warning trefoil) colored magenta or black on a yellow background. Lettering should be either magenta or black.
3. Signs shall be conspicuously posted at each access point, clearly worded, and, where appropriate, may include radiological control instructions. Radiological postings should be displayed only to signify actual or potential radiological conditions. Signs used for training should be clearly marked, such as “For Training Purposes Only.”
4. Posted areas should be as small as practicable for efficiency.
5. Postings should be maintained in a legible condition and updated based upon the results of the most recent radiological surveys.
6. If more than one radiological condition (such as contamination and high radiation) exists in the same area, each condition shall be identified.
7. In areas of ongoing work activities, the dose rate and contamination level or range of each should be included on, or in conjunction with, each posting as applicable.
8. Postings at entrance points to areas of ongoing work activities controlled for radiological purposes should state basic entry requirements, such as dosimetry, radiological work permit (RWP), or other written authorization, and respiratory protection requirements.

9. Rope, tape, chain, and similar barriers used to designate the boundaries of posted areas should be distinctive (i.e., yellow and magenta or yellow and black in color).
10. Physical barriers should be placed so that they are clearly visible from all directions and at various elevations. They should not be easily walked over or under, except at identified access points. These barriers shall be set up such that they do not impede the intended use of emergency exits or evacuation routes.
11. Areas shall be clearly and conspicuously posted. Posting of doors should be such that the postings remain visible when doors are open or closed.

Starting with the largest area posting requirement, *Controlled Areas* should be established where there is a radiological area or where radioactive material is present. The controlled area warns individuals that they are entering an area controlled for radiation protection purposes and they will not receive a total effective dose exceeding 100 mSv per year.

The next most restrictive area would be a *Buffer Area*. The buffer area provides a boundary to minimize the spread of contamination and to limit doses. For radiation doses, the buffer area should be set at a distance far enough from the exposure so that at the boundary of the buffer area, personnel do not receive more than 100 mSv per year total effective dose. Additionally, buffer areas can be used at the entrance or exit points for contamination areas to limit the spread of contamination while doffing protective clothing (DOE, 2008).

As mentioned above, there are six typical postings. These six are likely to encompass all the required postings for liquid radioactive waste tanks at Al-Tuwaitha. The posting criteria for the three types of radiation areas are listed in Table 1. The posting requirements for contamination area, high contamination area, and airborne radioactivity area are listed in Table 2.

Table 1. Radiation Area Posting Criteria (DOE, 2008)

Area	**Criteria**	**Posting**	**Supplemental Posting**
Radiation Area	Radiation levels could result in an individual receiving greater than 0.05 mSv per hour at 30 cm	"CAUTION, RADIATION AREA"	"RWP and PERSONAL DOSIMETER REQUIRED FOR ENTRY"
High Radiation Area	Radiation levels could result in an individual receiving greater than 1 mSv per hour at 30 cm	"CAUTION, HIGH RADIATION AREA" or "DANGER, HIGH RADIATION AREA"	"PERSONAL DOSIMETER, SUPPLEMENTAL DOSIMETER, AND RWP REQUIRED BEFORE ENTRY"
Very High Radiation Area	Radiation levels could result in an individual receiving greater than 500 rad per hour at 100 cm	"GRAVE DANGER, VERY HIGH RADIATION AREA"	"SPECIAL CONTROLS REQUIRED FOR ENTRY"

Table 2. Contamination Area and Airborne Radioactivity Posting Criteria (DOE, 2008)

Area	**Criteria**	**Posting**	**Supplemental Posting**
Contamination Area	Removable contamination levels (dpm/100 cm^2) greater than regulatory values but less than 100 times regulatory values	"CAUTION, CONTAMINATION AREA"	"RWP AND PROTECTIVE CLOTHING REQUIRED BEFORE ENTRY"
High Contamination Area	Removable contamination levels (dpm/100 cm^2) greater than 100 times regulatory values	"CAUTION, HIGH CONTAMINATION AREA" or "DANGER, HIGH CONTAMINATION AREA"	"RWP AND PROTECTIVE CLOTHING REQUIRED BEFORE ENTRY"
Airborne Radioactivity Area	Airborne concentrations (μCi/ml) above background are either greater than applicable DAC values, or would result in an individual without a respirator receiving an intake greater than 12 DAC-hrs per week.	"CAUTION, AIRBORNE RADIOACTIVITY AREA" or "DANGER," "AIRBORNE RADIOACTIVITY AREA"	"RWP AND PROTECTIVE CLOTHING REQUIRED BEFORE ENTRY"

Accessible areas where items or containers of radioactive material are used, handled or stored should be posted as "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL."

Areas with underground radioactive materials should be posted as "UNDERGROUND RADIOACTIVE MATERIAL," with supplemental postings to warn personnel to "Consult Radiological Control Organization before Excavation." This would be the case around tanks located outdoors with underground process piping leading to the facility. Soil surface contamination is clearly an issue within the Al-Tuwaitha site as seen in Chesser, 2009. Therefore, soil contamination will need to be posted around the site. Areas that have radionuclide contamination levels above Iraqi regulatory guidelines need to be posted as "CAUTION, SOIL CONTAMINATION AREA" with supplemental postings to warn personnel to "Consult Radiological Control Organization before Excavation."

Finally, within the radiation and contamination areas described above, *hot spots* may exist where localized radiation levels exceed 100 mSv per hour on contact and are 5 times greater than the general area dose rate. These hot spots should be marked and posted with a "CAUTION, RADIATION AREA: HOT SPOT." Examples of all the radiological postings discussed previously are shown in Figure 6.

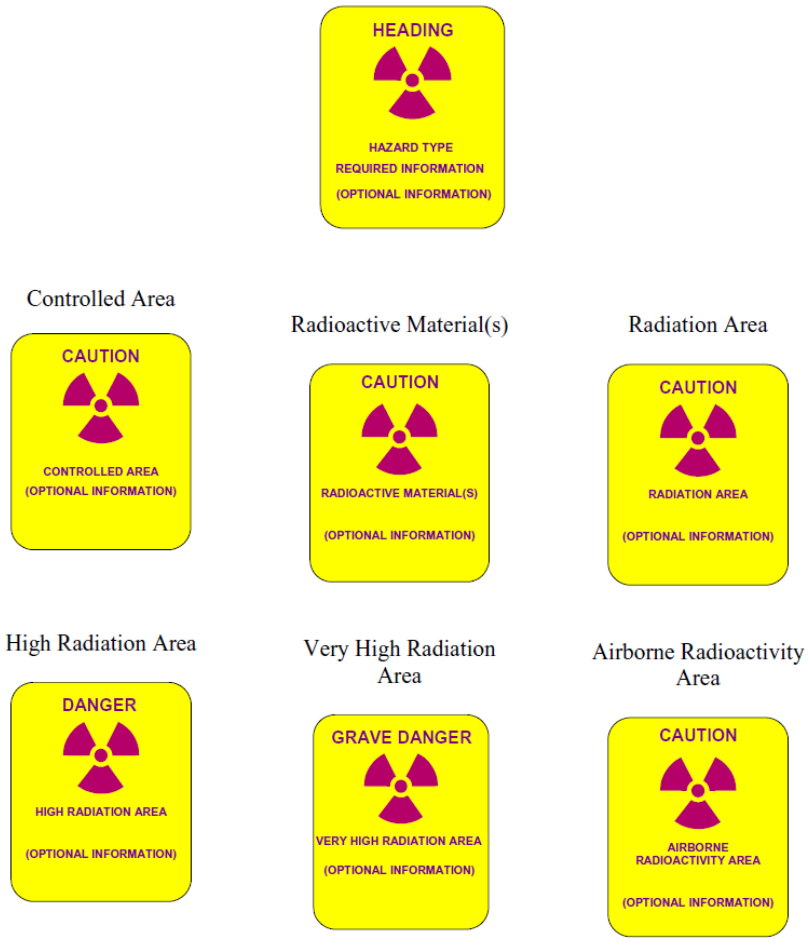

Figure 6. Radiological Signage

Access control to sites containing liquid radioactive waste tanks is not only important to limit radiation exposure, but to protect the health and safety of personnel from non-radiological hazards. At a minimum, controlled areas should require:

- appropriate radiological signage;
- access restrictions in the form of barriers, roped off areas, fencing with gates, etc. (the level of access restriction should be commensurate with the hazard it is restricting);
- locked entrance ways if necessary;
- all personnel who enter wear protective clothing and personal dosimetry; and

- Radiation Technicians accompany all radiological workers, especially during site characterization.

4.2 Tank Segregation

The purpose of this section is to purpose methods for minimizing the environmental hazard from the remaining tanks. Where appropriate, steps should be taken to segregate the waste tanks from the surrounding environment. Some items to consider follow:

- External tanks, for instance those at Tammuz-2, should be covered to limit water ingress. Methods for preventing water ingress could include sealing all currently open access points to the tank and placing a sturdy canopy over the external, bermed waste tanks. These recommendations to provide coverage to external tanks apply to all sites where the tank is exposed to the open environment.
- If the tanks are covered with a structure, such as those in the large Russian Silo complex, adequate drainage should be provided to divert water runoff away from the tanks to prevent subsurface damage or leaching. Therefore, the design for any sump or retention pond that has the potential to become contaminated (even if it is not considered a radioactive system) should include a liner and the capability for isolation or collection and routing of overflow to a monitored release path.
- For tanks with remaining liquid radioactive waste, secondary containment should be provided to prevent the spread of any leakage from the inadvertent opening of piping or drains. Some tanks already reside in containment pits; however, even those tanks that have secondary containment in sub-level basements may require additional means to limit liquid spread, such as plugging any drains.
- During tank characterizations and radiological surveys, all tank valves should be safely closed if possible.

- All debris and unnecessary structures, systems, and components should be removed from around the waste tank if they do not pose a radiological challenge. Removing debris around the tanks allows for both improved inspections and long-term, greater ability to monitor for leaks.
- Basement or pit drains should be identified. The ultimate termination point of these drains should be ascertained. If this is not possible, it would be preferable to remove the drain from service.
- In the long term, removal of waste from tanks should include designs that control and prevent radioactive system leakage and provide systems to detect leakage, identify the source in a timely manner, and mitigate the potential for widespread contamination.

5.0 Routine Maintenance and Monitoring

The purpose of this section is to instruct MoST on what should be done to maintain and monitor tank locations. This management plan does not purport to develop a comprehensive decommissioning and demolition plan for the liquid radioactive waste tanks. Reaching that level of detail would require much more GOI regulatory consideration and a much more comprehensive management plan encompassing all phases of the project from planning to quality control and documentation. What is purposed here is to lay the initial groundwork for future remediation of the waste tanks, pending decision on waste disposal options and technology. Since no structure for radioactive waste disposal exists in Iraq currently, maintenance and monitoring is the only logical solution to dealing with the liquid radioactive waste tanks in the near term. Once the tank sites are all accessed as outlined in Section 3, and appropriate controls are enacted to maintain the tanks in a standby condition as outlined in Section 4, then the GOI can consider alternatives for ultimate disposal and dismantlement of the tanks.

A scheduled monitoring plan for the liquid radioactive waste tanks after safe, secure access to all sites includes the following steps:

- Install radiation alarms in areas where tanks are determined to still contain regulatory-significant quantities of radioactive material.
- Inspect tank exterior for visual leaks once every month. Record results in log sheet maintained until final decommissioning.
- Inspect tank exterior for corrosion, paying special attention to pipe joints and weld locations. Record results in log sheet maintained until final decommissioning.
- After an initial radiological survey for each site during the characterization phase, conduct a re-survey every month for those sites where work is not being performed.
- Radiological postings and controls should be inspected every month to ensure integrity and hazard warning accuracy. The postings should be changed as necessary to reflect the actual radiological hazard.

All of the above information should be included in a log sheet for each tank site using the tank nomenclature presented in Appendix B and kept for the life of the decommissioning activities at Al-Tuwaitha.

6.0 Soil Sampling and Borehole Monitoring

The purpose of this section is to broadly discuss how to couple a soil sampling plan with tank investigation, how to prioritize the tanks, and provide a high-level overview of soil sampling and borehole monitoring which is more comprehensively addressed in companion documentation (see Copland, 2011). An important part of maintenance and monitoring of the liquid radioactive waste tanks is performing underground soil samples around the external waste tanks and beneath the buildings containing waste tanks and process equipment, such as the RWTS. Determining the soil contamination around waste tank sites will assist in site characterization and planning for further remediation. Including soil sampling guidance, Sandia has developed a groundwater monitoring program in separate documentation (see *Groundwater Monitoring Program Plan for the Al-Tuwaitha Nuclear Research Center (Copland, 2011)*). Additional guidance for

crafting a soil sampling plan can be found in IAEA TECDOC-1415, *Soil Sampling for Environmental Contaminants* (IAEA, 2004).

6.1 Planning

It is expected that all tank sites at Al-Tuwaitha will be part of a soil sampling program which can serve in a dual capacity. First, it can be used initially to determine the sub-surface soil contamination adjacent to and beneath the waste tanks. Second, the boreholes for soil sampling can be used to monitor any subsequent leaks from the tanks that are known now to have remaining radioactive liquid contamination.

Because the extent of sub-surface contamination is not well know at Al-Tuwaitha, systematic soil sampling should produce a spatial map of contamination concentration. This information can be used to prioritize which tanks should be internally sampled, further segregated from the environment, or placed on an increased monitoring schedule. Soil sampling should be focused on the two categories of tanks discussed in Section 2.2. Higher priority tanks, such as those with in-ground piping and no secondary containment, would be prime candidates for timely soil sampling. The remaining tanks, such as those with secondary containment or little liquid present, could receive lower priority for soil sampling.

6.2 Sampling

Once the drilling locations have been mapped around all tank locations, the soil sampling method should be determined. Because several of the waste tanks are located in building basements, lateral soil boring will be necessary to access beneath buildings. Therefore, the building basement depth must be determined to conduct appropriate angled boreholes, which will also dictate the distance the borehole will need to be started from the structure. A soil sampling program plan is developed in companion documentation and can be found in the Sandia report *Groundwater Monitoring Program Plan for the Al-Tuwaitha Nuclear Research Center* (Copland, 2011).

Limited analytical capabilities or cost considerations may dictate that soil samples will be shipped out of the country for analysis. However, if gamma spectroscopy equipment is available, some soil samples can be analyzed for radioisotopes on-site. This would give a good indication on what tank contaminants have leached into the soil, and what radiological concerns may exist.

6.3 Borehole Monitoring

Once soil sample boreholes have been drilled beneath and around waste tanks in a structured fashion to characterize the soil contamination in the area, the boreholes can be utilized for continuous monitoring of tanks that are determined to contain substantial amounts of liquid radioactive waste in the characterization phase outlined in Section 5. Radiation monitors can be placed in select boreholes to continuously monitor for increases in radioactivity. Elevated levels of radioactivity could indicate radionuclide migration from the waste tank or migration from adjacent sites. Additionally, leak monitors can be placed in select boreholes to monitor for increases in moisture content. Further information on borehole monitoring is provided in the Sandia report *Groundwater Monitoring Program Plan for the Al-Tuwaitha Nuclear Research Center* (Copland, 2011).

7.0 Summary and Conclusions

The purpose of this report is to develop a project management plan for maintaining and monitoring liquid radioactive waste tanks at Iraq's Al-Tuwaitha Nuclear Research Center. The site contains approximately 30 identified waste tanks that contain varying amounts of liquid or sludge radioactive waste. Because the site has remained in disrepair due to several wars, military destruction, dismantlement and intrusion, the GOI is embarking on an internationally supported program to remediate the site under guidance from Iraq's Ministry of Science and Technology. Successful decontamination and decommissioning (D&D) of the Active Metallurgical Testing Laboratory has shown that Iraq can successfully carry out a non-radiological facility D&D. The only remaining structures at the LAMA facility are two hot cell facilities that would require similar

radiological controls as those applied to the waste tanks. Therefore, transitioning to radiological D&D is a natural progression in the cleanup effort, and tackling the safety hazard the tanks pose is crucial to remediating the site.

Until the GOI can establish sufficient regulatory controls and a waste disposal policy, the tanks and contaminated material are considered to remain in a standby condition with monitoring and maintenance. The first step in this approach is fully characterizing the extent of the problem as this is integral in ascertaining the scope of the cleanup effort and will assist in policy decisions and, later on, in the ultimate disposition of the waste material. To begin the characterization process, the GOI and Sandia National Laboratories have begun to develop a liquid radioactive waste tank database, as seen in Appendix B, to catalog characteristics of waste tanks at Al-Tuwaitha. Much of the information in this database is based on personal accounts and limited documentation. With this information collected, this project management plan attempts to embark on a conservative path for the GOI to begin addressing the problem. This is further complicated by limited resources and regulatory controls, but guidance in this document attempts to firm up those links and equip personnel with the information necessary to develop safe processes for characterization and cleanup. To that end, this project plan outlines 11 major tasks for the GOI to accomplish so that the tanks can be characterized and ultimately monitored using soil borings and in-bore monitors. The 11 major endeavors are as follows:

1. Acquire radioanalytical equipment from vendors, such as Canberra or Ortec, for radiological surveys and waste characterization. This develops a domestic capability to analyze tank samples and further develops the radioanalytical capability within the GOI. Appendix C discusses radioanalytical techniques useful for radiation surveys and waste characterization and makes limited suggestions for useful equipment in each category.
2. Perform a tank hazard assessment. This screening will establish the safety protocol for initial debris removal and access to those tanks that reside in structurally unsound buildings or are blocked from easy investigation. This step will also formalize a work planning and controls document that includes a

radiation work permit (RWP), or equivalent. This will establish a protocol for personnel to conduct their work in a predefined and safe manner, where the anticipated hazards can be understood and anticipated. It also ensures that personnel are aware of the risks associated with the work they are performing.

3. Remove debris and prepare the site for active tank interrogation. Many of the tank sites are inaccessible and thus engineering evaluation and construction activities may be required to prepare the site for personnel. Several of the sites are already readily accessible (i.e., Tammuz-2 external tanks, Russian Silos, and IRT-5000 external tanks), and therefore this step will be limited. Radiological surveys can commence at these sites following implementation of the appropriate work process and controls.
4. Conduct a formal radiological survey of each tank area. The personnel at Al-Tuwaitha have conducted a limited dose survey of accessible tanks. This survey included external tank dose rate and background dose rate from a clean, stainless steel scrap tank. The formal radiological survey will require a dose map showing the facility layout and location of radiological hazards in the controlled area. Additionally, the survey will be part of an ongoing monitoring program, which will be updated every month in conjunction with a tank inspection.
5. Post radiological areas and maintain access controls for those areas where the dose limits exceed prescribed values. Part of protecting health and safety is alerting individuals to the hazards surrounding them. Not only is this a formal part of the radiation work permit, it is also an integral part of determining tank integrity.
6. Inspect the tanks both visually and through non-destructive means. The simplest avenue for the GOI to assess tank integrity is to visually inspect a tank and its surrounding. This phase involves developing a detailed description of a tank, including serial number, material, corrosion, leakage, valve alignment, damage, etc. Further non-destructive measurements can be employed if the budget is sufficient for that technology. Finally, as capabilities permit, conduct surface contamination surveys. Assuming the tanks can be accessed after a

hazard assessment is developed and impediments are removed, surface contamination and doses will be need to be obtained for all tanks and recorded.

7. Routinely maintain and monitor the tanks using inspection, radiation monitoring, and soil monitoring. The simplest approach for tank monitoring is to schedule visual inspections, especially in those instances where waste tanks have secondary containment in a pit or basement. Leaks should be noticeable through timely inspections. Additionally, in-room active radiation monitoring and soil monitoring can provide indications of leaks that are otherwise not visible. Through inspection and radiation monitoring, the postings and controls can be maintained commensurate with the hazard.
8. Segregate tanks from the environment. Even though the facility is located in an arid climate, waste tank water ingress should be minimized to impede any further radionuclide transport to the surroundings. Some tanks contain little-to-no remaining radioactive material and will take low priority in this step. However, those tanks that contain predominantly sludge or cake will need secondary protection. This task also involves closing any openings, including valves, access ports and man-holes.
9. As capabilities and safety documentation permit, acquire samples from inside a tank to determine radioactive material composition (liquid, sludge or cake, and radionuclides). Various methods are available to obtain samples in a safe and remote manner while minimizing the radiological risk to personnel. Part of this phase will require determining the domestic analysis capability and the need to ship samples outside the country. These steps are described in Appendix D.
10. Obtain soil samples at predefined locations for each waste tank. Boreholes for soil samples can start and run concurrently with all above tasks. The GOI must first develop a borehole plan and apply the appropriate sampling technology. Domestic sample analysis capabilities may need to be developed or contracted.
11. Place radiation and moisture monitors in boreholes around the waste tank sites. Angle borings beneath the waste tanks can be utilized as in-situ monitoring for radionuclides and tank leakage. Since most tanks are not buried underground,

visual inspection will provide the first indication of leakage; however, angle bore monitoring can provide delayed indication that a leak as occurred and the subsequent plume magnitude.

The 11 tasks presented above are recommended in a logical fashion to facilitate a project schedule for three years. Figure 7 presents the proposed project schedule for the Al-Tuwaitha liquid radioactive waste tank maintenance and monitoring program.

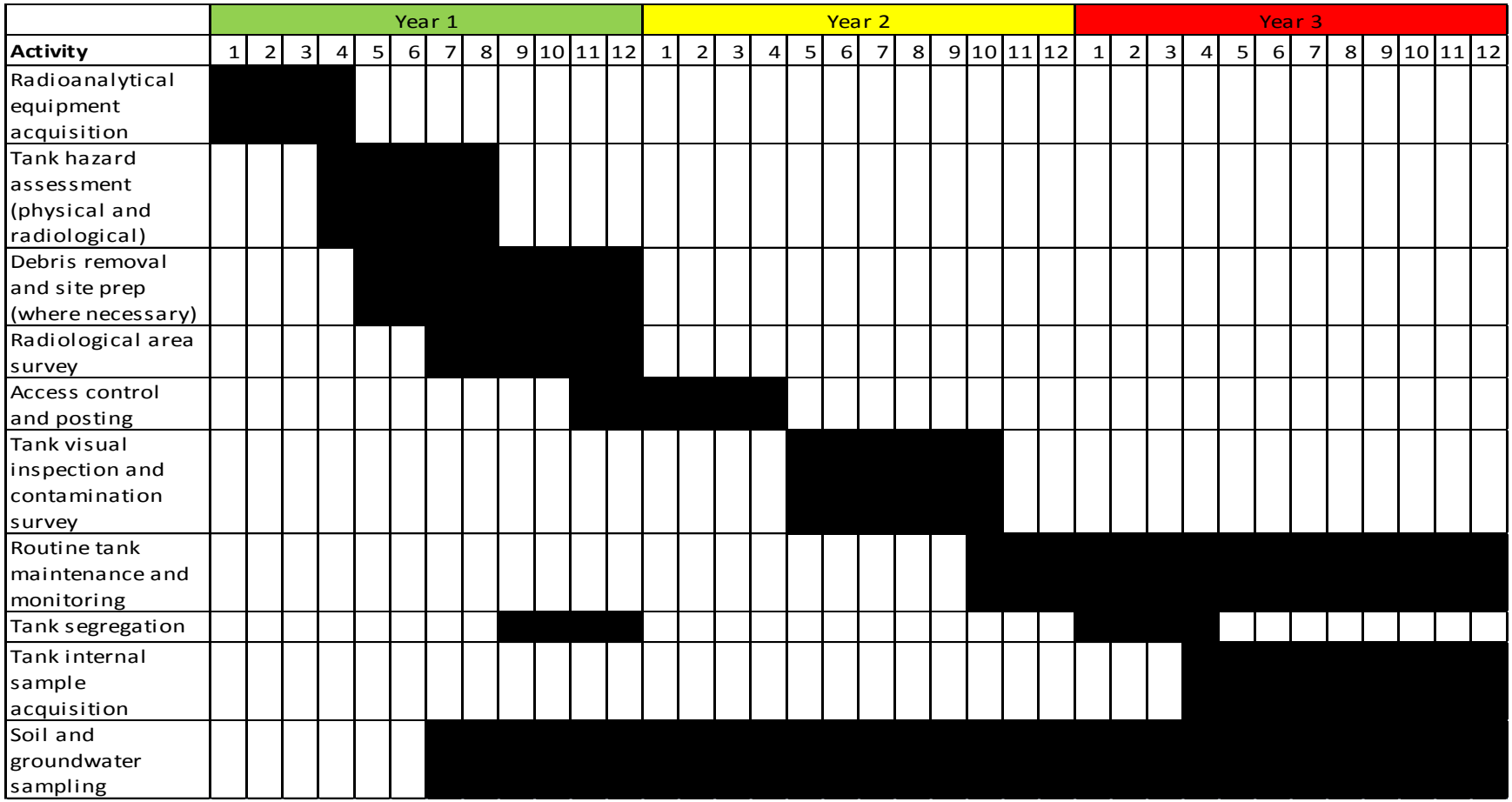

Figure 7. Notional Liquid Radioactive Waste Tank Project Schedule

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Appendix A. 2007 IAEA Overview of Status of Nuclear Facilities at Al-Tuwaitha

STATUS OF NUCLEAR FACILITIES IN IRAQ
Consolidated Data – Roger Coates / G Healey
Version November 2007

Based on document "Final Version – 24 November 2006 – G. Healey"

Introduction
This document is intended to describe the status of facilities in Iraq that were involved with handling nuclear materials, how waste materials were produced and what happened to them, where contaminated materials are located and how they became contaminated. Further, note is made of what data is or is not available about the facilities from a decommissioning / contamination point of view. The information given is, essentially, from memory and review of a few documents, thus, the accuracy is not guaranteed. However, the current version of this document has been subject to review by Iraqi experts and represents the best current overview of the Iraqi nuclear facilities.

1. Al-Tuwaitha
Tuwaitha was virtually a "one-stop-shop" for the Iraqi nuclear program. Very basically, activities at Tuwaitha could be considered as two parts, radioisotope/irradiation activities and U conversion activities. Relevant buildings are listed in numerical order.

1.1 Building 9 Radiochemistry Laboratory
- Italian-supplied equipment and labs
- Building 9 housed hot cells where reprocessing and chemical extraction activities (mixersettlers) for Pu (and other nuclides including Po) extraction were conducted
- the hot cell area was heavily damaged but the glove box line for Pu work survived
- concrete was poured inside some of these glove boxes by IAEA inspectors to make them unusable
- areas outside the glove boxes are contaminated, but not heavily
- the internals of the glove boxes will have Pu contamination
- there is a 5 m^3 tank believed to be full of High Level Liquid Waste from the reprocessing facility. The access to the tank is very difficult.
- it is possible that there may be buried contamination at the opposite end of the building from the hot cells (a suspicion from the Inspection Team).
- some years ago, there existed an underground storage tank outside at the rear of the extraction area. It gave high radiation readings. There will be piping connection from the extraction area to the tank. A brief attempt to locate this tank in June 2003 failed, but efforts should be made to locate it.
- estimated currently 55 te solid waste and 5 m^3 High Level Liquid Waste

1.2 Building 13 IRT 5000
- Russian-supplied pool-type research reactor: went critical in 1967 as IRT 2000 (upgraded 1978 to IRT 5000)

- used for isotope production and neutron source
- still exists in heavily damaged condition
- physically dangerous area
- heavy contamination in foundation/basement structures and remaining equipment, plus activation of the core structure and surrounding shielding
- estimated currently 85 te solid waste and 55 m^3 liquid waste
- there is a liquid waste tank outside the building containing small quantity of radioactive liquid waste

1.3 Building 15A Italian Radioisotope Production [Isotope Production No 2]

- Bldg 15A totally destroyed during 1991 war and later completed by Iraq. Currently only two hot cells standing
- Italian-supplied facility
- There is tank located near to the building for liquid waste (contents unknown)
- Radioisotopes were transferred by cask from the building

1.4 Building 15B Russian Radioisotope Production [Isotope Production No 1]

- Russian supplied facility: sometimes referred to as the Russian Isotope Production Building
- purpose was to produce medical isotopes from irradiations in IRT
- Liquid wastes was sent initially to a tank which is outside the building
- underground transfer system between IRT and Bldg 15B
- underground systems still in place
- informal surveys showed no surface contamination [but may be some spotty contamination around the adjacent Building 14]
- underground situation is unknown

1.5 Building 22 LAMA

- French-supplied facility
- building still exists but in heavily damaged condition
- never used for intended purpose; thus very little nuclear material ever processed (see below).
- a processing line was installed to extract enriched U but only did one test using one unirradiated natural U batch. There are some references to previous Li alloy processing, so H3 contamination may also be possible.
- contents of concrete hot cells were totally removed by Iraqi authorities and the concrete hot cells were decontaminated
- other hot cells in LAMA were dismantled and it is reported that no contamination was found on lead recovered from these cells (lead was sent offsite under IAEA supervision for battery manufacture). There was some contamination on lead and it was decontaminated
- any residual contamination in LAMA is believed to be minor

1.6 Building 24 Tamuz 2

- French-supplied pool-type research reactor went critical in 1980: 500kW thermal
- ruins still exist and are in danger of collapse: physically dangerous area

- light contamination and heavy activation in foundation/basement structures and remaining equipment
- estimated currently 50 te solid waste and 35 m^3 liquid waste
- links to Tammuz 1 reactor via water channel; Channel 3 goes from Tammuz 2 to Channel 2 which links to two Hot Cells (contaminated). Channel 1 links Channel 2 to Tammuz 1 but was isolated and should be clean.
- [NB Tammuz 1 reactor destroyed in 1981 prior to fuel load: not generally part of this decommissioning project since clean, except for possibility of contaminated resins used for cleaning water from water channels and Tammuz-2 reactor pool]
- Image 076 – ruins of Tamuz 2 1991 to present

1.7 Building 35 Radioactive Waste Treatment Station [RWTS]

- French-supplied facility (circa 1981)
- building still exists and has been repaired to some extent.
- diluted high level liquid wastes present in tanks (2?) in shielded room
- low level wastes present in tanks (3 at least?) in separate room
- diluted high level liquid waste tank present in a sub-floor room
- types of isotopes and quantities stored in the waste tanks is not defined/known fission product and actinide

  [Iraq preliminary data suggests the following:
  1.25 m^3 tank containing 0.25 m^3 H/MLW (3 Ci total, ie 0.4MBq/ml)
  10 m^3 tank full M(?)LW (1500Bq/ml)
  5 m^3 tank full LLW (900Bq/ml)
  2 m^3 tank full LLW (900Bq/ml)
  1 m^3 tank full LLW ex-laundry (?Bq/ml)
  1 m^3 tank containing 30 liters LLW ex-laundry (100Bq/ml)
  This information needs to be correlated with the above provisional data on tanks]
- considerable piping, all contaminated, associated with tank storage
- [Note: how did liquors arrive at RWTS? Pipework existed between facilities in the French Complex – RWTS, Tammuz 1 and 2, LWB (clean) and LAMA.
- RWTS had facilities for compacting and bituminizing rad waste
- estimated currently 50 te solid waste and 25 m^3 of medium and low active liquid waste
- surface contamination exists is spotty areas in surrounding ground areas. Mainly U compounds associated with contaminated equipment storage

1.8 Building 36 Solid Waste Storage Silo [Monolat]

- French-supplied silo facility
- still exist in good condition
- little known of the contents (no documents): some waste may have come from the Italian B73 complex.
- some storage of low-level solid wastes

1.9 Building 39 RWTS Warehouse/ Waste Store

- warehouse contains a vast assortment of solid waste including contaminated equipment

- large number of concrete containers, many housing bituminized waste
- high radiation levels with some concrete containers
- large number (1000+) metal drums, many holding contaminated contents (estimated 1200 drums containing around 250 te contaminated sludge, at least some of which came from the B73 complex)
- some drums contain U compound residues
- numerous empty contaminated drums
- some drums contain medical isotope waste
- in June 2003, medical wastes were littering the floor inside in front of the access gate
- contaminated equipment contains U3O8, yellowcake, UO3
- practically every item in the building is contaminated to some extent
- the building floor is heavily contaminated
- estimated currently 8 te solid waste (destroyed equipment, mainly U contamination), plus bituminized waste and drummed sludge

1.10 Contaminated ground areas surrounding Building 39

- Outside the building is a liquid waste transfer truck – it is contaminated and some liquid is still probably present in the tanks.
- Miscellaneous waste in the surrounding area is currently estimated at 50-60 te yellow barrels of contaminated soil from Al-Jesira, plus around 50 te of scattered metallic waste.

1.11 Building 40 Russian Silos

- still present but in decayed state. Roof structure might be unsafe
- used for both solid (98 wells/silos) and liquid waste
- liquid wastes evaporated to solid many years ago
- former liquid waste tank still shows high activity: some waste probably originated from the IRT upgrade but the origin of the higher activity waste is unknown.
- contents of the silos and liquid tank are unknown
    i. 98 wells/silos contained about 20-30 te solid waste from IRT (including upgrade) 1967-90
    ii. 70-80 te solid waste added around 1991 from unknown origin
- known leakage to ground after nearby bomb explosion - further information on ground contamination would be desirable.
- surrounding ground areas show spotty contamination
- there were unconfirmed rumors of buried contaminated items in the surroundings

1.12 Building 64 Uranium Metal Production

- made around 10 kg of UF4
- All equipment was removed and building cleaned (as part of concealment activity)
- now down to concrete base level
- Decommissioning may not be required – just confirmation of no activity in the area.

1.13 Building 73A Fuel Fabrication and Building 73B U Purification (including 73.4 Waste Pit)

- Italian-supplied facility (part of B73 Italian complex)

- a conversion plant that purified yellowcake to produce UO3, U3O8, UO2, UF4 and U metal.
- plant was heavily damaged during the 1991 war and today, only a steel skeleton remains.
- Spotty surface contamination can be found in the surroundings originating from the movement of contaminated equipment etc.
- There remains some sub-floor piping in the ruin which contains U compound. This is the piping that connected the purification equipment to a small waste storage area.
- Building73B: U Purification (Technological Hall) – joined to Building 73A: may have subfloor pipework connections- the open areas between Building 73 and the Berm were used in the past as a vast scrapyard of damaged equipment. Spotty surface contamination could be found in this area and some buried contaminated item might still exist. Care should be taken in this area because acid waste, particularly HF acid was buried - currently estimated 10 te solid waste
- Treat B73 and the adjacent open area as a single facility for planning purposes: essentially a common open area.

Building 73B Waste Pit [B73.4]

- located nearby Building 73
- consists of a concrete pit housing two stainless steel tanks
- One tank contained inactive liquid waste
- One tank housed liquid uranium bearing waste as a sludge
- Most of the sludge tank contents were removed in 1998, probably to the B39 Warehouse
- The bottom of the pit still contains a thin sludge (unless it has by now dried out): this remaining sludge was estimated to contain about 150 kg U as U oxides.
- There is spotty surface contamination in the pit area
- Two truck body containers used in the 1998 recovery operations are contaminated

1.14 Buildings 73 C and D Other Italian Complex

- B73C: Utilities Facility - possible spotty surface contamination due to cross contamination
- B73D: Fuel Element Thermal Test: had a rig to heat fuel elements (may not have used real fuel)
- This group will be considered as a single facility for this project

1.15 Building 85 Technology Hall (Uranium Tetrachloride Preparation and Purification Labs)

- principally the home of UCl4 development and production
- also housed waste recovery activities
- building damaged during 1991 war and then raised to the ground by Iraqi authorities - site then buried by rubble and soil
- Uranium compounds almost certainly were buried in the foundation structures
- Material balance calculations by the Action Team indicate that any buried quantity of U would be quite small, possibly less than 100 kg (use as pessimistic assumption).
- Surface contamination was never found in the Building 85 area.

1.16 Building 155?? Po 210 Production

- Referred to as Building 155 on some lists, but this notation not known to Iraqi staff
- Building purpose and activity to be determined, but listed as a Po210 facility. Not clear whether this building was active (to be confirmed)
- Building may have been severely damaged
- Note that Building 66 Physics Lab was intended for Po work but did not go active

1.17 OUT-1 Burial/Concealment Location

- OUT-1 is located outside the berm, adjacent to the perimeter road, on the West side of Tuwaitha. It was a concealment location used for uranium compounds evacuated from Building 85 (possibly up to 100 kg U).
- Numerous small containers of solvent extraction fluid and uranyl nitrate plus small containers and vials of U compounds were placed in concrete containers and buried beside the road.
- Additionally, about 40 plastic containers of uranyl nitrate were buried in scattered fashion in the adjacent marsh area
- Examination confirmed the presence of plastic containers and yellow staining of soil in the marsh area, but no liquid contents were found. Most of the containers probably broke open when they were being covered over.
- Snakes might be present in this area (one found during original examination)

1.18 Scrap yard(s) and Burial Sites

- Further information required: numerous scrap areas around the site (including eg around the Italian area) project
- Contaminated scrap was looted during 2003 events- contaminated equipment and probably waste materials were buried at Tuwaitha. A ground area near the Tuwaitha Fire Station was heavily used for this purpose
- EMIS equipment was buried at several locations. The extent of contamination is not known.
- Information about burial activities exists in AT reports, but there will be no information about quantities of nuclear material.
- listed here as a general reminder that all ground areas on Tuwaitha have the potential to have had previous usage for disposal/burial or miscellaneous temporary storage

Amended
International Atomic Energy Agency
November 2007

Related Document: “Relating to Al Jesira and Adaya Dump Situation” GJ Healey (November 2006)

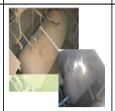
Appendix B. Al-Tuwaitha Liquid Radioactive Waste Tank Database

Legend
Radioactive Waste Treatment Station = RW1, RW2, etc.
Russian Radioisotopes production = RR1A, RR1B, RR2C, RR2D
IRT Reactor = IR1, IR2, etc.
Tammuz-2 reactor = TA1
Fuel Fabrication = FF1, FF2, etc.
Russian Silo = RS1, RS2
LAMA Lab = LM1
Italian Radioisotope Production = RP1, RP2, etc.
Radiochemistry Laboratory = RL

Appendix B References

(1) Cochran, J.R. and J.J. Danneels, 2009, "Sandia National Laboratories Support of the Iraq Nuclear Facilities Dismantlement and Disposal Program," SAND2009-1732, Sandia National Laboratories, Albuquerque, NM.
(2) Rasheed, M., "Surveillance, Characterization, and Contingencies of Liquid Waste," Presentation to IAEA, Vienna, April 2008.
(3) Emad Sol Shamsaldin, Personal Communication, February 2010.
(4) Zaboon, "Plan for Monitoring and Controlling Radioactive Liquid Waste Tanks," Presentation to IAEA, Vienna, 2010
(5) Zaboon, Personal Communication on spreadsheet, June 2010.

Tank Name	RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8	RW9	RR1 A	RR1 B	RR2 A	RR2 B
Picture								No Picture	No Picture				
Tank Facility Location	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Radioactive Waste Treatment Station (RWTS)*	*Russian Radioisotope Production*	*Russian Radioisotope Production*	*Russian Radioisotope Production*	*Russian Radioisotope Production*
Building Number (1)	35	35	35	35	35	35	35	35	35	15B	15B	15B	15B
Tank Material	SS304	SS304	SS304	SS304	SS304	SS304	SS304	Concrete Pit (5)	Concrete Pit (5)	SS304	SS304	SS304	SS304
Engineering Drawings Available													
Reused/Scraped	Reuse	Reuse	Reuse	Reuse	Reuse	Reuse	Reuse			Reuse	Reuse	Reuse	Reuse
Connected Underground Piping (Yes/No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes (IRT to 15B) Yes (possible tank at rear of extraction area)	Yes (IRT to 15B) Yes (possible tank at rear of extraction area)	Yes (IRT to 15B) Yes (possible tank at rear of extraction area)	Yes (IRT to 15B) Yes (possible tank at rear of extraction area)
Secondary Confinement (Type)	Yes (first floor) (5)	Yes (first floor) (5)	Yes (first floor) (5)	Yes (first floor) (5)	Yes (first floor) (5)	Yes (first floor) (5)	Yes (first floor) (5)			Yes (first floor) (5)	Yes (first floor) (5)	Yes (first floor) (5)	Yes (first floor) (5)
Accessibilty Description	first floor of building (5)	first floor of building (5)	first floor of building (5)	at the pit -2 m (5)	first floor of building (5)	first floor of building (5)	first floor of building (5)			Open Building (5)	Open Building (5)	Open Building (5)	Open Building (5)
Rated Capacity [m^3]	60 (5)	60 (5)	60 (5)	10	2 (1) 3 (2,4) 1.5 (5)	? / 2 tanks (2) 20 (5)	? / 2 tanks (2) 20 (5)			2 x 100 (2) 4 x? (2)	2 x 100 (2) 4 x? (2)	2 x 100 (2) 4 x? (2)	2 x 100 (2) 4 x? (2)
Estimated Remaining Quantity [m^3]	Empty (5)	Empty (5)	Empty (5)	10 (1,5) ~10 (2,4)	2 (1) < 1 (2,4) 0.5 (5)	empty (5)	empty (5)	2 (5)	5 (5)	Empty (5)	Empty (5)	Empty (5)	Empty (5)
Percentage Liquid	0	0	0	100 (5)	30	0	0	100	100	0	0	0	0
Percentage Solids/Sludge/etc.										100	100	100	100
Material Origin	Treatment of RW (5)	Treatment of RW (5)	Treatment of RW (5)	Decontamination (2) RadChem Waste Treament (4) Drainage (5)	Concentration (2,4,5)	Drainage (2,4)	Drainage (2,4)			Probably IRT Upgrade	Probably IRT Upgrade	Probably IRT Upgrade	Probably IRT Upgrade
Radionuclides				Co60,Cs137 (2,4,5) FP (4,5)	Co60,Cs137 (2,4) FP (4,5)	Co60,Cs137 (2,4)	Co60,Cs137 (2,4)						
Activity Concentration (Bq/ml)				1500 (1)	900 (1)	100 (1)	100 (1)			High	High	High	High
Activity Concentration (Ci/m^3)				0.04	0.02	0.0027	0.0027						
Dose Rate (µSv/h)				64 @ 1m (4)	46 @ 1m (4)					0.176 (4)	0.096 (4)	0.053 (4)	0.063 (4)
Notes	MLW (5)	MLW (5)	MLW (5)	MLW (4)	HLW (4)	MLW	MLW					LLW (5)	LLW (5)

Tank Name	RR3[a]	RR4[a]	IR1[a]	IR2[a]	TA1	FF1[c]	FF2[c]	FF3[c]	RS1	RS2	LM1	RP1	RP2	RP3	RP4	RL
Picture												*INACCESSIBLE*	*INACCESSIBLE*	*INACCESSIBLE*	*INACCESSIBLE*	*INACCESSIBLE*
Tank Facility Location	*Russian Radioisotope Production*	*Russian Radioisotope Production*	*IRT-5000 Reactor*	*IRT-5000 Reactor*	*Tammuz-2 Reactor*	*Fuel Fabrication Building*	*Fuel Fabrication Building*	*Fuel Fabrication Building*	*Russian Silos*	*Russian Silos*	*LAMA*	*Italian Radioisotope Production*	*Italian Radioisotope Production*	*Italian Radioisotope Production*	*Italian Radioisotope Production*	*Radiochemistry Laboratory *may have 2-3 tanks*
Building Number (1)	15B	15B	13	13	24	73 A/B	73 A/B	73 A/B	40	40		15A	15A	15A	15A	9
Tank Material	Concrete	Concrete	Concrete	Concrete	SS304	Concrete Pit	SS304	SS304	Concrete	Concrete	SS304	SS	SS	SS	SS	SS
Engineering Drawings Available	2 openings (4) 70 cm opening, 5 m depth (5)	2 openings (4) 70 cm opening, 5 m depth (5)	70 cm opening, 5 m depth (5)	70 cm opening, 5 m depth (5)		Stair Damage (5)	Stair Damage (5)	Stair Damage (5)								
Reused/Scraped	Reuse	Reuse	Reuse	Reuse	Scraped	Scraped	Scraped	Scraped	Scraped	Scraped	Scraped					
Connected Underground Piping (Yes/No)	Yes (5)	Yes (5)	Yes (5)	Yes (5)	Yes (5)		Yes (5)	Yes (5)			Yes (5)					Yes (possible tank at rear of extraction area)
Secondary Confinement (Type)	No (Tank on Berm) (5)	No (Tank on Berm) (5)	No (Tank on berm)	No (Tank on berm)	Yes (basement level -4)	No (pit)	Yes (in pit)	Yes (in pit)	No (Tank on Berm) (5)	No (Tank on Berm) (5)	Basement (-4)m level (4) Yes (basement level -3) (5)					Yes (basement?)
Accessibilty Description	Open Area (5)	Open Area (5)	Open Area	Open Area	Open building -3m (5)	Open Area	Open Pit at grade	Open Pit at grade	Open Area (5)	Open Area (5)	Underground (-4 m) (5)	Underground and inaccessible (2,4,5)	Underground and inaccessible (2,4,5)	Underground and inaccessible (2,4,5)	Underground and inaccessible (2,4,5)	Underground and inaccessible (5)
Rated Capacity [m^3]	100 or 100/2 (4) 100 (5)	100 or 100/2 (4) 100 (5)	100 (4)	100 (4)	3 (5)		3 (4,5)	3 (4,5)								5 (1) 10 (2,4)
Estimated Remaining Quantity [m^3]	Empty (5)	Empty (5)	55 (1) Little (2) 0 or sludge (4) Empty (5)	Little (2) 0 or sludge (4) Empty (5)	~1 (2,4,5)	Empty (5)	sludge (4) Empty (5)	sludge (4) Empty (5)	Empty (5)	Empty (5)	Empty (5)					5 (2,3,4)
Percentage Liquid	0	0	0	0	20 (5)	0	0	0	0	0	0					5 ??
Percentage Solids/Sludge/etc.	100 (4)	100 (4)							100 (4)	100 (4)		100 (4)	100 (4)	100 (4)	100 (4)	
Material Origin	Probably IRT Upgrade	Probably IRT Upgrade	Work Activity (2) reactor primary (4,5)	Work Activity (2) reactor primary (4,5)	Work Activity (2) reactor primary (4,5)		Yellowcake Fuel Fabrication (5)	Yellowcake Fuel Fabrication (5)								Fuel Reprcessing (1,2,4)
Radionuclides			Co60,Cs137 (2,4,5)	Co60,Cs137 (2,4,5)	Co60,Cs137 (2,4,5)	Natural Uranium (5)	Natural Uranium (5)	Natural Uranium (5)	Co60,Cs137, others	Co60,Cs137, others	Trace Tritium (5)	Co60 (4)	Co60 (4)	Co60 (4)	Co60 (4)	FP, Actinides (1,2,4)
Activity Concentration (Bq/ml)	High	High		[70-140 µR/h] (2)		[90 µR/h] (2)	[65 µR/h] (2) 1.31 µSv/h (4)		"High Activity"		[90 µR/h] (2)					
Activity Concentration (Ci/m^3)																
Dose Rate (µSv/h)	0.097 (4)	0.095 (4)	0.644	0.113	0.051		1.31 µSv/h (4)	0.18 µSv/h (4)	0.98 (4)	0.98 (4)						
Notes			LLW	LLW	LLW		MLW (5)	MLW (5)	One liquid tank may be spent fuel pool	98 wells/silos probably used for solid waste		LLW	LLW	LLW	LLW	

Appendix C. General Information on Radioanalytical Methods and Associated Equipment

The purpose of this section is to identify equipment that could be used to characterize radioactive waste tanks at Al-Tuwaitha. In order to conduct radiological surveys, remove potentially contaminated debris, and sample material within the tank, the GOI will need the appropriate equipment and technical capability. Discussion in this section on radioanalytical methods is a combination of guidance from IAEA Technical Report Series No. 462, *Managing Low Radioactivity Material from the Decommissioning of Nuclear Facilities* (IAEA, 2008), and the U.S. Environmental Protection Agency, *Inventory of Radiological Methodologies for Sites Contaminated with Radioactive Materials* (EPA, 2006).

The methods used to determine different radioactive contaminates and their levels are divided into three major categories: screening methods, routine methods and specialized methods. In the initial stages of tank characterization and hazard assessment, screening and routine methods will be predominately utilized. Specialized methods will usually require off-site laboratory testing or more expensive equipment acquisition.

C.1 Screening Methods

Using screening methods, it is possible to identify circumstances requiring immediate actions. The screening methodologies may also allow personnel insight into choosing which more sophisticated methodologies or analytical techniques.

Screening methodologies will generally be relatively quick (minutes to hours), are not radionuclide-specific, require instrumentation that is not sophisticated and can be used with a minimal degree of user training. An additional advantage is that considerable time is saved, because these techniques do not employ chemical separations. MoST personnel currently possess basic survey equipment discussed in the following sections, but the quality or specific models possessed are not discussed in this report.

Site-specific action levels that are established early in the cleanup process may be adjusted as additional data are assessed. Preliminary screening levels may initiate immediate response activities, or may indicate that radionuclide-specific methodologies should be used for more definitive measurements. For example, emergency response or removal could be triggered by the results of a screening method above a certain threshold. The action levels may need to be flexible enough to expand the scope of investigation for potential radionuclides so that the initial assessment can accurately depict the problem.

C.1.1 Gross Alpha and Gross Beta Methods

These methods can identify the presence of radionuclides that emit alpha or beta particles. The measurement made will identify the total number of particles detected per unit time, but not the amount or type of each radionuclide that may be present. Gross alpha and beta measurements allow the comparison of measurements in the suspect area to measurements in nearby areas that are known to be free of the contamination under investigation. Some of these early investigations have been conducted by MoST personnel comparing easily accessible stainless steel liquid radioactive waste tanks to a radiologically clean stainless steel tank used for background count rate measurement. Because the specific identity of the radionuclide may not be a principal concern at this point, this analysis will identify the overall extent of the contamination in terms of gross quantity (measured in counts per minute, cpm) and areas affected (in land area measurement units as well as depth profile). If the gross-screening method is calibrated using a reference radionuclide, then analytical results will be reported in disintegrations per minute.

Detection methods commonly used for making screening measurements include:

- Alpha/beta survey-type detectors (usually hand held);
- Gas flow proportional counters;
- Liquid scintillation detectors; and

- Other devices that have a thin “window” (i.e., the detector covering) that will allow the emitted particles to interact with the detector.

These detection devices can differentiate between alpha particles and beta particles because their energies on the detector are significantly different. However, without chemical separation, no significant information about specific radionuclides can be gained by the gross alpha or beta count rates.

Individual radionuclides will be either alpha or beta emitters (most of these will also emit gamma radiation as a result of the alpha or beta decay). Alpha or beta particles emitted by different radionuclides may not have the same energies, and this will result in different detection efficiencies.

Some types of screening methodology may not be applicable to certain types of samples. For example an alpha/beta survey meter would not be readily applicable to a screening analysis of water samples for alpha emitters, nor would a liquid scintillation detector be applicable for direct analysis of soils.

C.1.2 Gamma Analysis

Four distinct detection methods exist for screening-level gamma analysis:

- Geiger-Mueller (G-M) detector with a “beta shield”;
- Cesium iodide [CsI(Tl)] detector (usually found only at research laboratories);
- Sodium iodide [NaI(Tl)] detector; and
- Germanium (HPGe) detector.

The four detection methods listed above are in order of increasing specificity and decreasing ease of field measurement. The G-M detector with the beta shield closed yields information regarding gamma emitters above a certain energy threshold (~100 keV depending on the thickness of the beta shield). The beta shield is a piece of metal (either steel or aluminum) that absorbs betas so they do not interact with the gas-filled chamber

of the counter. No information on the range of gamma energies or the specific radionuclides would be available from this technique. The instrument is hand held and needs no auxiliary equipment. The CsI(Tl) detector has low-energy resolution for gamma rays in the energy range of ~20 keV to 3,000 keV. It is very efficient, but it can only resolve peaks that are on the order of 150–200 keV apart.

The NaI(Tl) detector is sensitive in the range of ~20 keV to 2,500 keV, depending on the detector housing thickness and size of the detector. It can provide general information regarding the distribution of energies of the gamma emitters in the samples, and has a very high efficiency. However, it most likely cannot provide specific radionuclide identification. This is due to its limited ability to distinguish gamma rays that are less than ~50 keV apart. Newer instruments can be hand held, but older ones may need a high voltage power supply and cables.

The HPGe detectors can provide significant details regarding specific gamma emitting radionuclides. It can distinguish gamma rays that are within about 1.5 keV of each other. A recent application for this type of detection system is Canberra's FALCON 5000® Portable HPGe-based Radionuclide Identifier, seen in Figure 8. This unit is field-portable, doesn't require liquid nitrogen cooling, and covers a wide energy range. Obviously, if the radioactive material in question is not gamma emitting, then using this screening method may not provide useful information. These methods are used routinely in the laboratory. However, several adaptations to the detection system hardware exist that allow them to be used in the field.

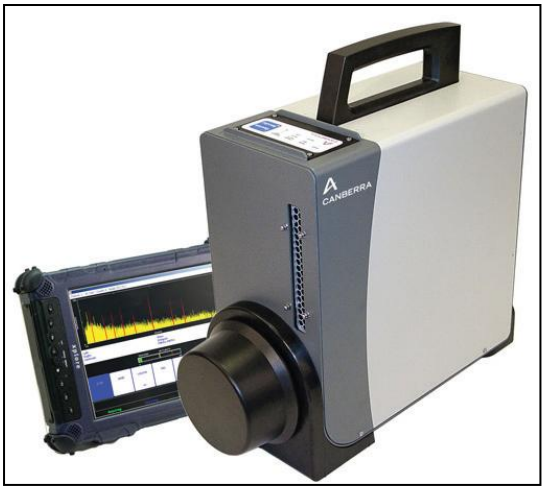


Figure 8. Canberra Falcon 5000 ® Portable HPGe Radionuclide Identifier
Image courtesy Canberra: <http://www.canberra.com/pdf/Products/MCA_pdf/C37433-Falcon-SS.pdf>

C.2 Routine Methodologies

In order to obtain radioactivity concentration for a specific radionuclide at environmental levels in soil or water media, chemical separations usually need to be performed. Data collected by these routine methodologies are often used to characterize the concentration and distribution of radionuclides, assess risk to human health and the environment, and potentially select technologies for treatability testing to evaluate the performance and cost of the treatment technologies that are being considered for cleanup. Because each treatment effort may be radionuclide- and matrix-specific, a method that can differentiate the various radionuclides is important.

There are many different analytical procedures for separation of radionuclides from each other in water and soil matrices. In each case, the chemical (i.e., elemental) characteristic of the analyte is used for separating it from each of the other elements that may be present. Separation techniques, such as precipitation, electroplating, or evaporation, are used to minimize the volume of the sample fraction to be analyzed. The routine methods are identified in the next sections.

C.2.1 Gross Alpha and Gross Beta Methods

The analysis of radionuclides using these general methods of detection includes

- Gas proportional counting;
- Liquid scintillation counting; and
- Cerenkov counting (high-energy beta counting).

Each of these methods relies on effective chemical separation to determine low-level activity and discriminate specific radionuclides (i.e., eliminate other radionuclides that might yield a positive count rate when the radionuclide of interest is not present). Their major advantages are that these methods generally have high detection efficiency and may minimize the sample counting time to achieve a specific Minimum Detectable Contamination (MDC). Their disadvantage is that they lack the energy discrimination necessary to distinguish alpha or beta particles of different energies.

C.2.2 Spectrometric Methods

The methods that can be considered spectrometric are:

- Alpha spectrometry; and
- Gamma spectrometry [either HPGe or NaI(Tl)].

Alpha and gamma (HPGe) spectrometry is very discriminating because of the high resolution of the solid state detectors they use. Thus, the identifying photon energies from ^{134}Cs and ^{137}Cs can be separated using gamma spectrometry, and the identifying alpha energies from ^{241}Am and ^{243}Am can be separated using alpha spectrometry.

C.3 Specialized Methodologies

In contrast to measuring radioactive decay emissions, specialized methodologies, specifically mass spectrometry, detect and measure the number of atoms of an element or isotope in a sample by either emission of UV radiation from an excited state or by atom counting, respectively. Mass spectrometry is used when there is a need to distinguish

isotopes of the same element from one another. This becomes important when the contamination may be from different types of sources.

C.3.1 Mass Spectrometric Methods

Conventional techniques for radiochemical analysis are based on the chemical properties of radionuclides that allow them to be separated from all other stable elements in the mixture of the sample. At times it is extremely important to identify the specific isotopic mixture of some radionuclides (e.g., U, Pu, Np, and Am) in order to determine the source of the contamination.

Three different methods that are based on the same principle, charge-to-mass ratio of the ionized atom, can be used to identify the specific isotopic ratios of radionuclides. These are:

- Accelerator Mass Spectrometry (AMS);
- Thermal Ionization Mass Spectrometry (TIMS); and
- Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

In each one of these methods, the sample is vaporized into its elemental constituents, and the elements are ionized and passed through a mass spectrometer. The distinct advantage of these methods is that the separation is based on the mass of the isotopes involved and not on their chemical nature. Thus, analysis of several different radionuclides, as well as different isotopes of a single element, can be performed simultaneously. This type of analysis would most likely not be used in the initial phases of a site evaluation due to the specific nature of the analysis. However, during later phases, these methods could be used to collect site-specific data sufficient to characterize site conditions. They might also be used after remediation activities have been implemented to assess whether or not speciation of uranium or plutonium isotopes is necessary.

Currently, ICP-MS techniques are best suited for radionuclides with half-lives greater than about 10,000 years, when more sensitive analyses are required (such as for

environmental levels of ^{239}Pu) or when isotopic analyses are required to separate isotopes whose decay emissions prevent separate quantification (such as ^{240}Pu from ^{239}Pu). Methods employing specialized radiochemical separations and the most sensitive mass spectrometers are currently being developed for radionuclides with shorter half-lives, such as ^{90}Sr.

Appendix D. General Information on Sampling and Characterizing Tank Contents

This section discusses developing a tank characterization plan to determine external tank contamination and obtain internal samples. Prior to personnel obtaining internal samples for ex-situ radiological examination, the radiation hazards surrounding the tanks need to be analyzed. Additionally, a characterization plan and its results will provide data used for decisions on future demolition and decommissioning activities involving liquid radioactive waste tanks.

Characterization is a final step in the maintenance and monitoring process and requires a logical approach in order to obtain the data necessary for planning the ultimate disposition of the waste tanks. The characterization program provides radiological information on the tanks, which enables decisions on other steps such as decontamination, dismantling, and removal of components and equipment; demolition of structures; management of waste; and the funding of activities. In their guidance on *Radiological Characterization of Shutdown Nuclear Reactors for Decommissioning Purposes* (IAEA, 1998), the IAEA prescribes necessary components for a comprehensive characterization program:

1. review of historical information;
2. implementation of calculation methods;
3. preparation of the sampling and analysis plan based on an appropriate statistical approach;
4. performance of in situ measurements, sampling and analyses;
5. review and evaluation of the data obtained; and
6. comparison of calculated results and measured data.

In light of the unique circumstances at Al-Tuwaitha, components 1, 2, and 6 have little benefit to the characterization process. Since all historical information from the program

practically vanished, most historical information is based on anecdotal personal information. As discussed previously, no know engineering drawings exist for liquid radioactive waste tanks. Recent discussions in 2010 indicate that the GOI may obtain some assistance from the French firm that originally constructed the Radioactive Waste Treatment Station. A sister facility to the RWTS exists in France, but until a formal agreement is in place, this management plan will assume that the only historical information available is from references cited in Appendix A for the liquid radioactive waste tank inventory. Therefore components 3, 4, and 5 are most applicable in implementing a characterization plan.

Component 3: Sampling and Analysis

The sampling and analysis plan defines the quality of data necessary to achieve the characterization objectives. The plan should define the following:

- types, numbers, sizes, locations, and analyses of samples required;
- instrument requirements;
- the radiation protection aspects or controls of the activity;
- data reduction, validation, and reporting requirements;
- quality assurance (QA) requirements;
- methodology to be employed when taking the samples and performing the analyses; and
- requirements for disposal of waste generated during sampling.

Appropriate reviews of the plans should be made and may include input by specialists in the areas listed above. The level of confidence required in the results defines the number of samples or measurements required and their desired locations. Finally, the plan for sampling and analysis is significant in developing a specification for Quality Assurance (QA) requirements. For example, if the results of a characterization program will have regulatory or health and safety implications, or if they will be used to determine the necessity of procuring expensive equipment for waste treatment, the samples must be subject to the highest QA standards. In contrast, if the results suggest fewer health and

safety or regulatory implications, and if changing direction during decommissioning is not difficult, QA requirements may be less stringent (IAEA, 1998).

Component 4: Performance of In Situ Measurements

In situ measurements and/or samples should be taken on various components that can be reasonably accessed. If possible, it is also desirable to obtain samples of irradiated and/or contaminated materials such that laboratory analyses may be performed to determine individual radionuclide activities and concentrations. However, this process can be expensive and difficult for highly activated components and structures where trace amounts of sample material can produce radiation dose rates in the range of Gy/h (IAEA, 1998). Therefore, given the current capabilities within Iraq, it is unlikely that work would proceed on any waste tank location where excessive on-contact dose rates dictated remote manipulation or excessive shielding. However, where dose rates fall below acceptable occupational exposure guidelines, further radionuclide characterization and tank contaminate mitigation would be warranted.

Component 5: Review and Evaluation of Data Obtained

Measurement data should be analyzed as early as possible to develop a sufficient characterization of the facility and to determine whether or not the data requirements are being met. It is expected that characterization plans may change during the conduct of the characterization as a result of these ongoing assessments. Departures from the plan may be appropriate, for example, where contamination is more extensive than originally anticipated and a greater number of samples are necessary to characterize the full extent of contamination. As another example, trends in measurements made may indicate that the sampling plan in use will not give the desired results. The plan can then be amended by altering the sampling technique, changing the frequency, or redefining the regions where the measurements are to be carried out. Reviews should continue during sampling and analysis to allow for early detection of errors or anomalies so that corrections or alterations can be made without affecting the whole process.

Site characterization approaches should also be flexible enough to permit remediation of any contamination identified during the course of site characterization. For instance, if

relatively small volumes of contaminated materials that can be safely handled during characterization are identified, they should be removed in accordance with radiation protection protocol and transferred to a disposal or collection area for disposal in accordance with established regulations and license conditions. The responsible party should properly document the detection, extent, removal, and transfer of the contaminated waste to confirm, during subsequent review of decommissioning activities, that the materials were removed and relocated in an appropriate manner (IAEA, 1998).

D.1 External Contamination

Radiological hazards are likely to exist not only in the tanks, but on structures, systems, and components surrounding the suspect tank. Contamination could exist on any number of locations outside a tank and within its spatial facility location. Since most of the tanks were used for processing, it is unlikely that any will be neutron activated; however, some tanks, such as the Russian Silos, could conceivably contain reactor activated material. The external contamination will be determined in a step-wise manner utilizing hand-held instruments and smear samples.

D.1.1 Hand-Held Total Measurements

Gross radiation measurement will be conducted on all tanks and proximal equipment using hand-held radiation detectors described in Appendix C. Determining the α, β, and γ dose or exposure rate will identify radiation hazards and assist in posting and radiological controls discussed previously in Section 4. These measurements should be made at a fixed distance from surfaces (usually 30 cm and 1 meter). Results from hand-held measurements should be logged in a spreadsheet with location, date, time, and a drawing of the physical layout (referred to as a radiological survey map).

Conducting a radiation dose rate survey should include the following:

1. Obtain radiation levels for the general area for all types of radiation. Hold survey instrument at waist level or use an extendable radiation survey meter to increase

the distance from potentially high radiation sources. Survey measurements taken at the top, middle, and bottom of the tank, as allowable, can yield useful information on the tank liquid level. This can performed before, and in addition to, the internal visual inspections described later.

2. Obtain dose rate measurement for all items at 1 meter, 30 cm, and on contact. The 30 cm reading will dictate the posting requirements for the area.
3. Obtain beta radiation measurements using an ionization chamber or other appropriate equipment. If using an ionization chamber, obtain a closed and open window measurement.
4. Obtain a beta eye dose using the ionization chamber with the window open and an aluminum filter 30 cm from the source.

D.1.2 Removable Contamination

Removable contamination samples will be taken for all tanks and proximal equipment by taking a piece of material such as filter paper and rubbing it over a specified area of the component surface (usually 100-300 cm^2).

Conducting a surface contamination survey should include the following:

1. Select a suitable collection media, such as filter paper, masslin, or sticky pads. Number the collection media or collection bag appropriately so that the location of sample collection can be recorded on a survey map.
2. Swipe an area of 100 cm^2 if counting directly in the field; if transferring to another location, swipe 300 cm^2. Swipe gently so as not to spread or disturb potential contamination.
3. Scan the swipe with an appropriate portable survey instrument.
4. If positive radioactivity is detected, count the sample for 1 minute, minimum. Include a similar background count rate with the sample count rate.
5. Place the sample in a labeled container that corresponds to the item or location identified on the radiological survey map. The sample can be analyzed at a later time for isotopic composition using gamma spectroscopy.

D.2 Internal Tank Analysis

Since only estimates exist for radionuclide quantity in the 30 liquid radioactive waste tanks, an important part of the characterization process is obtaining samples of the sludge, cake, or liquid remaining in each of the tanks. Internal tank samples cannot be obtained until the individual tank hazard assessment, debris removal, and site preparation are complete as discussed in Section 3. Assuming that the GOI has gained safe access to each of the currently inaccessible tanks, a first step would be to perform a visual inspection inside the tank, followed by obtaining samples of tank contents.

D.2.1 Internal Visual Inspection

The following steps outline a process for conducting visual investigation inside the tank. Personal protective equipment, such as disposable protective clothing, will be required while performing hazard removal, site preparation, and previously conducted external radiological surveys for the posting and controls. Because otherwise previously sealed tanks may have been opened for internal analysis, personnel must implement contamination control methods. Some suggested guidance for working in potentially contaminated areas and handling equipment that could become contaminated follows:

1. Utilize disposable protective clothing to protect against skin contamination, including nitrile gloves, rubber shoe covers, or coveralls with foot and head protection.
2. Minimize personal items worn under protective clothing, inspect for holes prior to use, and protect wrists by taping gloves to coverall sleeves and wearing a second set of gloves over first set. Outer gloves can be changed as needed to prevent the spread of contamination.
3. Avoid getting protective clothing wet, unnecessary contact with contaminated surfaces, and disturbing contamination causing it to become airborne.
4. Respiratory protection should be provided based on air sampling during the radiological survey. Additionally, air sampling and monitoring using

continuous air monitors is suggested while tanks are opened and during internal analysis.

5. Before entering the controlled area, plan what items are necessary to complete the planned work. Limit the amount of material, equipment, and tools taken into the radiation or contamination area. Anything taken into the area could potentially become contaminated. Utilize laydown areas for material, equipment, and tools to minimize the spread of contamination.
6. All items taken into the area should be surveyed for contamination prior to removal.
7. Remove protective clothing in an orderly manner and dispose of in proper receptacles. While removing protective clothing, do not touch exposed clothing or skin.
8. Upon removing protective clothing and exiting a contamination or radiation area, personnel should perform a whole-body frisk.

Following the contamination control methods listed above, tank internal inspection could proceed as follows:

1. Using appropriate machinery or tooling, vent stacks or access ports located at the top of the waste tank may need to be removed to provide internal tank access. Accessing the tank penetrations anywhere below the top of the tank should be avoided to limit release of any material.
2. Conduct visual inspection via remote video surveillance or inspection through tank access openings (contingent on radiological survey). Visual inspection within the tank can be accomplished using a radiation hardened (if necessary) small-space camera specifically designed for nuclear applications. An example is provided in Figure 9.
3. Internal visual inspection can determine the percentage of material remaining in the tank and locate any internal degradation not hidden by waste material. These observations should be recorded along with information ascertained in

Section 3.5.1 to show internal structural integrity, the physical consistency of the remaining material, and the voided capacity of the tank.

Figure 9. Color MEGRAD Camera.
Image courtesy of Ahlberg Electronics AB (<www.nuclear-cameras.com>)

Introducing equipment into the tanks raises the potential for that equipment to become contaminated. Any equipment, tools, or materials used within the controlled area around liquid radioactive waste tanks could require decontamination if it is to be reused and transferred to a different tank site. Therefore, basic decontamination guidance for equipment is provided below, based on ASTM Standard D5608, "Standard Practices for Decontamination for Field Equipment Used at Low Level Radioactive Waste Sites."

1. Reasonable efforts should be made to minimize the contamination of non-sample contacting equipment, such as the digital camera discussed previously.
2. Equipment should be determined to be contaminated or clean based upon hand-held frisking and swipe tests prior to removal from the area.
3. Equipment that is determined to be contaminated should be transferred to a decontamination area, preferably within the controlled area.
4. Remove any solid material from the testing apparatus by scraping or brushing with tools made of inert, non-absorbent material.
5. If contamination exists after removing solid material, use a moist, lint-free paper wipe or towel to wipe the area clean using rinse water. The cleaning

materials will need to be disposed of as potentially contaminated waste, so minimize the amount of cleaning material utilized as practical.

6. Survey the equipment using hand-held friskers and perform swipe test to verify the hand-held survey and that the apparatus being decontaminated meets release criteria.

For exhaustive guidance on decontamination procedures, the reader is directed to the above referenced Standard, or one of the many ASTM Standards on decontamination protocol.

D.2.2 Liquid Level Measurement

Different techniques will need to be employed depending on the relative percentage of liquid, sludge, or solids in a tank. For those tanks that appear to be near 100% liquid, a first step would be measuring the liquid level to ascertain the volume and subsequent sample acquisition technique.

Direct Measurement Dipstick

Direct physical measurement using a dipstick is the simplest and most likely liquid level measurement technique due to cost-effectiveness, simplicity, and quick results. It can involve the use of a pre-measured tape or stick, with or without a sensitive paste, to determine the liquid level. The disadvantage to this measurement technique is its limitation in confined spaces. Where radioactive waste tanks do not have at least the same amount of space around them as the size of the tank, this technique would not be practical. However, a weighted rope could be dropped into a tank, removed and measured to the liquid line, but this technique introduces some serious contamination and radiological safety concerns. Personnel must access a tank opening, minimizing their distance and maximizing shielding from radioactive material and handling a contaminated piece of tooling. This technique would not be advisable unless strictly monitored.

Ultrasonic Level Detectors

A preferred liquid level measurement technique would be non-destructive external testing of the liquid level. Ultrasonic testing has the advantage of not requiring contact with the

waste, and in some instances does not even require access to the inside of the tank, thus avoiding tank penetration. Figure 10 provides an example of an ultrasonic level sensing probe manufactured by RS Hydro. Many commercial vendors provide level sensing equipment that could be utilized for tank waste characterization.

Figure 10. Ultrasonic Level Sensor
Image courtesy RS Hydro <http://www.rshydro.co.uk/The-Probe-pr-16338.html>

D.2.3 Sample Acquisition Protocol and Apparatus

The U.S. EPA provides excellent guidance for sampling tanks in their document *Waste Sampling Operating Procedure* (EPA, 2007). Most of the guidance for sample acquisition from liquid radioactive waste tanks is derived from this document. Additionally, U.S. EPA *Tank Sampling Standard Operating Procedures* (EPA, 1994) was used for procedural steps in accessing and sampling the tanks.

All 30 suspect tanks at Al-Tuwaitha are assumed to have contained radioactive waste at some point, or currently contain radioactive waste. The quantity, waste form, and isotopics are not well understood at this reports writing. Thus, obtaining tank samples and characterizing that sample through destructive analysis or gamma spectroscopy is crucial. There are a couple avenues for sampling the tanks. In addition to having discharge valves near the bottom of tanks, most tanks have hatches at the top. It is desirable to collect samples from the top hatch because of the potential for the tank's

contents to be stratified. Additionally, when sampling from the discharge valve, there is a possibility of a stuck or broken valve which could cause an uncontrolled release. Investigators should not utilize valves on tanks unless a containment plan is in place should the valve stick or break. If personnel must sample from a tank discharge valve, the valving arrangement of the particular tank must be clearly understood to ensure that the compartment(s) of interest is sampled.

Because of the many different types of designs and materials that may be encountered, only general sampling procedures that outline sampling a tank from the top hatch are listed below.

1. All relevant information concerning the tank such as the type of tank, the tank capacity, markings, condition, and suspected contents should be documented.
2. Personnel should inspect the ladder, stairs, or catwalk that will be used to access the top hatch to ensure that they will support personnel and their equipment.
3. Before opening, ground each metal tank using grounding wires, alligator clips, and a grounding rod or metal structure.
4. Place sampling equipment and sample containers near tanks(s) to be sampled.
5. Any vents or pressure release valves should be slowly opened to allow the unit to vent to atmospheric pressure. Air monitoring for explosive or flammable gases and toxic vapors should be conducted during the venting with the results recorded. If dangerous concentrations of gases evolve from the vent or the pressure is too great, leave the area immediately.
6. Touch tank opening equipment to the bolts in the hatch lid and allow an electrical conductive path to form. Slowly remove the bolts or hatch with spark resistant tools (brass or beryllium). If a pressure build up is encountered or detected, cease opening activities and leave the area.
7. Screen tanks for explosive or flammable gases and toxic vapors with air monitoring instruments. Note the state, quantity, number of phases, and color of the tank contents. Record all relevant results, observations, and information.

8. Select the appropriate sampling equipment based on the state of the material and the type of tank. Sampling equipment should be constructed of non-reactive materials.
9. Determine the depth of any and all liquid, solid, and liquid/solid interface, and depth of sludge using a weighted tape measure, probe line, sludge judge, or equivalent.
10. Collect liquid samples from 1 foot below the surface, from mid-depth of liquid, and from 1 foot above the bottom any sludge layer. This can be accomplished with a subsurface grab sampler or bacon bomb. For liquids less than 5 feet in depth, use a glass thief or Composite Liquid Waste Sampler (COLIWASA) to collect the sample.
11. Compare the three samples for visual phase differences. If phase differences appear, systematic iterative sampling should be performed. By halving the distance between two discrete sampling points, one can determine the depth of the phase change.
12. If possible, measure the inside diameter of the tank and determine the volume of waste using depth measurements.
13. Sludges can be collected using a bacon bomb sampler, glass thief, or sludge judge.
14. Record all information and label the sample containers appropriately. Transfer samples to radiation metrology laboratory for further analysis. Additionally, chemical analysis of the samples should determine the pH of remaining waste since acids (pH<7) can induce a fast steel degradation and alkaline salts (pH>7) can induce fast concrete degradation.
15. Close the tank when sampling is complete. Contaminated sampling equipment should be surveyed and labeled appropriately, and decontaminated as necessary.

As mentioned above, there are several typical tank sampling devices available. These devices are discussed in more detail below.

- Bacon Bomb Sampler: Designed for the collection of material from various levels within a storage tank. It consists of a cylindrical body, usually made of chrome-plated brass and bronze with an internal tapered plunger that acts as a valve to admit the sample. A line attached to the top of the plunger opens and closes the valve. A line is attached to the removable top cover which has a locking mechanism to keep the plunger closed after sampling.
- Sludge Judge: Used for obtaining an accurate reading of settleable solids in any liquid. The sampling depth is dependent upon the length of the sludge judge. The sampler consists of 3/4″ plastic pipe in 5-foot sections, marked at 1-foot increments, with screw-type fittings.
- Subsurface Grab Sampler: Designed to collect samples of liquids at various depths. The sampler is usually constructed of aluminum or stainless steel tubing with a polypropylene or Teflon head that attaches to a 1-liter sample container.
- Glass Thief: A simple glass tube. This tool is simple, cost effective, and quick, and collects a sample without having to decontaminate.
- Bailer: A positive-displacement volatile sampler appropriate for collection of water samples for volatile analysis. Other models include messenger and bottom fill bailers.
- COLIWASA: Permits sampling of multi-phase waste. It can have a section of tubing with a neoprene stopper at one end attached by a rod running the length of the tube to a locking mechanism at the other end. Manipulation of the locking mechanism opens and closes the sampler by raising and lowering the neoprene stopper. They are difficult to decontaminate, but disposable ones are available.
- Peristaltic Pump: Can be useful to pull out samples from tanks having lower activity liquid. All that is required is a small opening at the top (e.g., instrument probe or vent line) through which one can introduce a quarter or half inch flexible silicone or other suitable tubing to draw samples from different depths.

Many commercial products are available for tank sampling. As show in Figure 11, Stanhope-Seta manufactures a multi-level self-sealing sampler with detachable sample

containers which can be opened at the required depth by a snatch valve which reseals when the container is full.

Figure 11. Multi-Level Self-Sealing Sampler
(Image courtesy Stanhope-Seta, <http://www.stanhope-seta.co.uk/533/Multi-Level-Self-Sealing-Sampler>)

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