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Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Solid Waste Processing Center

Primary Opening Cells Systems, Equipment, and Tools

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PACIFIC NORTHWEST NATIONAL LABORATORY
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Summary

This document addresses the remote systems and design integration aspects of the development of the Solid Waste Processing Center (SWPC), a facility to remotely open, sort, size reduce, and repackage mixed low-level waste (MLLW) and transuranic (TRU)/TRU mixed waste that is either contact-handled (CH) waste in large containers or remote-handled (RH) waste in various-sized packages.

The vast and varying waste stream that is anticipated to enter this facility makes this an extremely complex challenge. In addition to the issues associated with handling RH-TRU waste, the SWPC will encounter containers sized anywhere from 1 gallon cans to 20ft x 13ft x 11ft boxes. The waste containers can be as heavy as 83,000 pounds, and the radiation levels can be as high as 20,000 R/hr at the container surface.

Another aspect that makes this project complex is the remote environment, where tasks are inherently more difficult. Seemingly easy everyday tasks can be quite problematic or impossible to achieve remotely. Operator vision is limited to two dimensions (no depth of field), audio feedback is limited to what microphones and noise canceling technology can provide, and the sense of physically feeling motions or forces is absent without extensive sensor technology.

The authors have considerable background in the development and deployment of remotely operated systems for radioactive waste retrieval, inspection and surveillance, and decontamination and decommissioning of equipment and facilities. The Pacific Northwest National Laboratory (PNNL) was tasked with assessing and providing general guidance on the following issues:

- Project feasibility
- What remote equipment would be required, and to what extent is that equipment available commercially off-the-shelf
- The extent to which technology development is required
- The feasibility of siting the proposed facility within T Plant.

PNNL’s assessment is based on a review of summary tabulations of the waste inventory, a preliminary list of processing requirements, and uses knowledge of other projects with related challenges. Based on analysis of this limited and preliminary information, the project appears to be technically feasible. All the tasks identified in the proposed process description can probably be performed using remotely-operated equipment. Some technology development will be required, mostly at the tool/waste interface, and a significant design integration effort will be required.

PNNL's experience suggests that successfully processing waste in this facility will require more effort than simply buying equipment and installing it in T Plant. Each element of the system must interact with many others, and these interfaces will include mechanical, electrical/utility, vision, communications, and operators. Each of these interface points must be carefully managed by a systems integrator to ensure that the systems can work together effectively when finally installed. While many of the systems are found as commercially available "catalog" items, they are almost all custom manufactured for the payload size, type, and motion required.

A systems integrator will need to be involved in all aspects of the project including development of the functions and requirements and the specification and selection of equipment. A highly qualified integrator will have the ability to understand the SWPC challenges, will be good at matching the SWPC needs with technology, and approach the project with a structured systems engineering perspective. Systems integration requires inductive reasoning and knowledge of a large number of topics/technologies gained through research and experience.

It is critical that the project not underestimate the challenges of developing this facility. Key aspects in effectively succeeding at this effort and controlling costs include:

- Clearly defining scope and requirements with the involvement of users and stakeholders.
- Understanding the need for process design and tool flexibility to counteract the extensive uncertainties that will be encountered.
- Completing thorough design integration efforts up front.
- Paying significant attention to tool development, testing and validation for all process tasks. Commercial off-the-shelf tools are not designed for remote deployment and operation and will require adaptation.
- Being cognizant of the human-machine interface complexities associated with the deployment of numerous remote systems in one space.
- Utilizing discrete event simulation to focus on the logical structure of the facility and the movement of material through it.
- Understanding maintenance requirements.
- Evaluating the risk and consequences of equipment failures.
- Establishing and maintaining a cold mock up for testing, operator training, and operational task planning prior to and during operation of plant.
- Establishing a relationship with Labor for the development of the SWPC's own specialist operators to perform all remote tasks and maintenance.

In performing this assessment, information was gathered on other remote facilities across the Department of Energy (DOE) complex including the West Valley Remote-Handled Waste Facility, the Idaho Advanced Mixed Waste Treatment Project, and the Oak Ridge Spallation Neutron Source Target Facility. Experts in the fields of hot cell operation, TRU assay, and criticality safety were interviewed, and detailed discussions were conducted with major equipment vendors.

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Figures and Tables

Introduction

The SWPC will process MLLW waste and TRU waste that is either CH in boxes/large containers, or RH waste in various packages. The processing activities are anticipated to include load-in of waste containers, opening of containers, removal of non-conforming waste, waste sorting, size reduction, dose rate measurement, TRU assay, container loading, container sealing, and container load-out.

The focus of this document is to elaborate on the significant technology integration effort required for success and to provide information on the types and availability of remote equipment that may be used. The equipment presented here is limited to what might be required for load-in/load-out of containers, and for use in and in proximity to the Primary Container Opening Cell of the SWPC, which is conceptually shown in Figure 1. The process functions will include container opening, waste sorting, and size reduction. To enable these activities, equipment may include overhead heavy lift cranes, gantry and manipulator systems, heavy duty transport devices (conveyors/rails), remote vision systems, shredders, and heavy duty hydraulic booms.

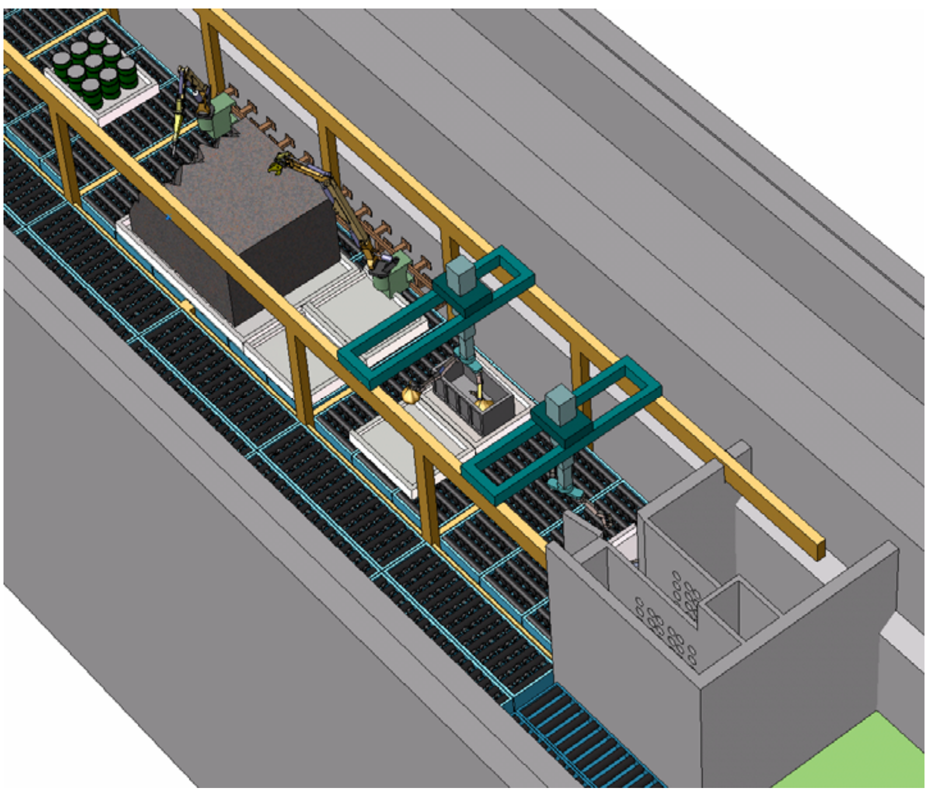

Figure 1. Concept Design

Sections of this document are devoted to Binding System Requirements, Understanding the Challenge, Design Integration, Example Equipment and Individual Component Integration, Equipment Risk/Consequence, System Integration, Cold Mock Up, Testing and Operational Approaches, and Procurement Strategies. Two appendices are included;

the first providing information on potential tooling and the second provides anecdotal processing information from the Advanced Mixed Waste Treatment Project.

The systems and design process discussed in this document are predicated on a pre-conceptual system design. This design is meant only to support project scoping activities. The final plant design may differ substantially from the reference design referred to in this document. Further, the basis for this design is a preliminary review of the waste inventory and a preliminary definition of requirements.

Binding System Requirements

Because the SWPC will be processing RH-TRU waste, there are some binding overall system requirements. These by no means constitute a complete list of project requirements, but they will significantly drive some of the more critical design and equipment constraints associated with the SWPC.

- The SWPC will be considered a hazardous environment with chemical contamination, high radiological dose (up to 20,000 R/hr at the container surface), and TRU radiological contamination.

- The SWPC will require remote operation. There will be no routine manual intervention in the RH-TRU processing cells. Visual operator feedback will be via remote cameras and monitors; audio will also be available via speaker and microphone systems. While the main cell will not be routinely accessible to operators, isolated decontaminated human-accessible maintenance bays (for cranes, gantries, manipulators, etc.) will be provided.

- Because of space constraints within T Plant, there will be no adjacent equipment galleries thus, there will be no standard mechanical master slave manipulators.

- The SWPC is to be designed to operate for at least 15 years.

- A wide range of container sizes and weights will need to be processed – from 1-gallon containers to boxes as large as 20ft x 13ft x 11ft. Container weights will be up to 83,000 pounds.

- Quick disconnects will be required for remote change out of tools and equipment.

- The design must minimize the number of “free” cables in process cells (tool umbilicals, equipment tethers, etc.)

Understanding the Challenge

For the SWPC to be successful, the remote systems within it must perform their tasks with minimal strain or fatigue on the operators, and they must work smoothly together. System success is predicated on the development of good equipment specifications. Good equipment specifications are developed from a thorough understanding of the challenge at hand (this entails detailed analysis of the waste inventory), a functions and requirements (F&Rs) document that fully bounds all foreseeable parameters without driving the design, and a clear conceptual design.

Waste Inventory

The waste inventory information developed via the Solid Waste Information Tracking System (SWITS) database and the Solid Waste Integrated Forecast Technical Report (SWIFT) database and report provide a rich environment of information. From these sources, the SWPC will need to gather as much information as possible regarding exactly what will be processed through this facility[1]. Critical information to be elicited from the inventory beyond information such as package size and weight include:

- What is the container made of?
- How the container was sealed (any gaskets, adhesives, etc.)?
- Is there a lid and how is it attached?
- Is there a detailed description of contents?
- How long have the contents been in the container?
- Known hazards (flammability, flighty contamination, dose levels, chemicals, etc.)
- What materials are present (both container and internals)
- Geometric shapes (containers and internals)
- Container dimensions
- Container age and condition
- Where has the container been stored and under what environmental conditions?
- Presence of free liquids?
- Does the container have a liner? If so, what is it made of, how thick is it, etc.
- Are there lifting bails and if so, where are they located?
- Filler material present? If so, what is it?

Additional information that will assist in the development of the functions and requirements may also be available on site. Consideration should be given to collecting information such as:

- Container fabrication drawings

[1] Non-destructive evaluation (NDE) will be used prior to waste container entry into the SWPC, and this will alleviate some informational concerns.

- Waste item drawings
- Waste container fabrication information – for example, were there a series of containers fabricated by one vendor in one large order?
- Information on practices in the field that were used during the original loading of these containers:
    - How were lead blankets and other heavy bulky items placed in the containers? (It is likely that the method for removal will be similar to the method of placement, and this will drive tooling requirements).
    - Is the inside of the box layered in plastic?
    - Will there be plastic around each item in the container?
    - Will there generally be loose debris (such as dirt) in the bottom of the containers?
    - Are like items packaged together or will each container have a random mix of waste?
    - Use and types of filler material – example would be a drum filled with pea gravel to fill voids.

With this type of information, it is possible to attempt to determine workable groups or classes of problems. These groupings can drive design decisions, as well as point out an opportunities for ‘campaigning’ (such as dose campaigns, contamination-level campaigns, etc.), and opportunities for automation, etc.

Inventory outliers should also be identified. Elimination of significant design drivers (where possible) can result in substantial cost savings. For example, if there is only one 83,000-pound box in the inventory and the remainder of the inventory is below 20,000 pounds, perhaps this big box should be handled separately. Or if one box is driving the height of the facility significantly more than any others, consider not handling that container in this facility, or consider doing some pre-processing prior to arrival at this facility.

Functions and Requirements (F&Rs)

Defining F&Rs is critical to selecting systems and tools that can successfully achieve the required project mission. One of the most prevalent reasons for lack of success in the use of remote systems is application of unsuitable remote systems to the task at hand.

Development of F&Rs should be completed with the full involvement of user, stakeholders, developers, and operators. All the critical partners need to own the process and ultimate outcome. Assumptions should be clearly documented up front in the F&R document.

F&Rs should cover all aspects of the scope including facility–specific (T Plant-driven) requirements, waste inventory-based considerations, disposition facility (Waste Isolation Pilot Plant [WIPP]-driven) requirements, and environmental and regulatory concerns. As an example, the WIPP-driven requirements will drive decisions regarding the waste output containers.

Requirements drive the design of the facility and the equipment within it. Each requirement needs to be scrubbed to define the basis for it, and then there needs to be an understanding of how that requirement is going to drive design and equipment decisions, and ultimately facility operation and cost.

Specific types of requirements may significantly affect the ultimate cost of equipment purchased from vendors. Examples of these include:

- Requiring vendors to supply H2 drawings
- Requiring all equipment be Underwriters Laboratory/Nationally Recognized Testing Laboratory (UL/NRTL) listed
- Requiring all equipment be non-sparking/explosion proof
- Requiring compliance with NQA-1
- No single-point failure requirements.

Once the detailed F&Rs are developed and formalized, it is critical that, to the greatest extent possible, they not be changed. Changing F&Rs mid design, fabrication or testing can dramatically increase project cost and schedule.

Design Integration

The SWPC will be a complex system that requires a continuing design integration effort to ensure that the various subsystems can operate together smoothly. Design integration is a large, complex, and iterative process requiring significant engineering judgment. It requires a complete understanding of the plant and how it will be operated, and begins as part of the conceptual design phase, and continues until the facility is commissioned. If integration issues are not addressed prior to facility design and equipment procurement, substantial rework will likely be required to retrofit equipment and components to meet facility needs.

Design integration efforts include considerations for operational flexibility, remote systems engineering perspectives, simulation and modeling, vendor expertise, identification of system operators and their functions, equipment interfaces, standardization, operations, balance of plant, contamination control and decontamination capability, criticality, equipment services, maintenance, planning for upset recovery and rework, and data collection.

The more complete and thorough the design integration task the fewer decisions will need to be made during final system integration, which is when the actual pieces of hardware are installed in the facility. It is possible to deal with mechanical interference, reach and fit issues during that phase, but it is considerably more expensive and often requires substantial rework to retrofit various components to allow the equipment to perform within the overall system environment.

Flexibility

A significant amount of effort will need to be placed on addressing the flexibility of each system in the process line. The system designers will need to plan for the unexpected and must incorporate system and tool flexibility to allow multiple approaches to different problems. This is to compensate for inventory information weaknesses, and the vast array of uncertainties associated with this type of operation. The facility will undoubtedly encounter variations in materials, lids, seals, coatings, geometric specifications, etc. for each type of "standard" container that has been used over the many years of Hanford operations. There will be uncertainty in bolt locations, drawing packages for containers and contents will not be accurate, dimensions will be erroneous, etc. The inventory may suggest there will be 250 4ft x 4ft x 8ft metal boxes with bolted lids; however by the time they reach the SWPC, 1/3 of these may have lids that have rusted shut, were welded shut, or are warped. In addition to these uncertainties, the process line/flow will require flexibility in operation to account for upset conditions, and equipment failures.

All of the elements of the system should have capacities in excess of the demands they are expected to support during operation. A trade off between cost, complexity, and capability will be present in every decision related to equipment selection. For example, additional lateral load capacity may be added into the gantry mast for a nominal cost, in the event that a future tool could exert more force than any existing tool on the system. In the event that a package came into the system and could not be opened with existing tools, and this flexibility was not designed into the system, then there may be no way to open that package.

Remote Systems Engineering

Design integration efforts will need to include remote operations perspectives. Activities here should include process layout, discrete event modeling, and tools versus process discussions. For example, the operators may have the capability to perform certain functions in the cell. However, performing those operations may result in a worse problem than what they were originally faced with. One example would be any action that results in large, heavy, flat pieces of material on the ground with no lifting bails. This would be considered a poor approach from a remote operations perspective, because it will be extremely difficult to pick that material off the ground.

Detailed remote systems engineering will consider simple and effective ways of approaching tasks in a remote environment, and developing approaches that "accommodate" the operational advantages and limitations of remote systems. This will require matching task functions to tools, and tools to deployment platforms that take into account the right motions to achieve the desired function. Cutting materials with a reciprocating saw on a manipulator can be done, but it is very difficult to keep the blade from bending or the saw from seizing once a cut has been initiated. An alternative is to use the manipulator to position the saw rather than to operate it. For example, a manipulator could be used to position linear guides for the saw. Once the guides are attached to the container, the manipulator would be used to position the saw, but let it run independently via the guides. Anytime there is a tool action that can apply significant force to a manipulator, there can be problems.

Simulation and Modeling

Simulation and modeling efforts will be a necessary element in the design integration process. Two areas of particular interest are discrete event simulation and continuous system simulation.

Discrete event simulation focuses on the logical structure of the overall processing facility, and the movement of material through it. Each processing station (air lock, main disassembly station, container opening station, etc.) will be incorporated into the model, and the flow of material through the entire facility can be studied. Issues such as choke points, maintenance outages and production throughput can be studied. Complete or partial breakdowns of different machines can be evaluated; this aids in the identification of critical spares, off-normal event recovery, and plant operation under various degraded-performance situations.

Continuous simulation is used to develop a time-domain model of each individual processing station. Issues that can be addressed by these models include reachability studies, mechanical interferences, camera positioning and viewability, operator training and interfaces with other regions of the cell.

A continuous event simulation will provide a graphical 3-dimensional representation of an individual machine or set of machines performing their tasks. This can be used for operator training (real operator controls can be used to drive the simulated on-screen machines). Machine work evolutions can be developed and studied for mechanical or workspace interferences, physical contact between different machines and reachability. Representative objects can be placed within the simulated workcell and machine locations evaluated to determine how easily the objects can be reached. Optimal machine position can be determined at a relatively low cost with this method. In simulations of this type, individual machines within the workcell can be controlled by computer programs. In the event that these programs are needed to control real systems, they can simply be downloaded from the simulation environment to the actual system. This type of simulation provides confidence that each individual workcell is optimally designed. It can also be adapted for training, and for use in a mock up facility to develop methods to recover from process upsets.

Together, these two kinds of models provide a powerful tool for understanding system and plant performance.

Vendor Expertise

Design integration involves leveraging the expertise of quality vendors to incorporate their product into the overall facility requirements. Instances will arise where a particular product must be modified to adequately function to achieve the facility mission. Decisions will have to be made as to whether a particular vendor is capable of performing the system modifications or whether it is best left to the integrator.

Equipment Operators

Design integration efforts will address the number of operators, what their jobs are, where their work area is, if they share control over any pieces of equipment, and which other operators they work with closely, etc.

Equipment Interfaces

It is important to identify which pieces of equipment may interface with other pieces of equipment. This does not only include mechanical interfacing, but also power/utility, vision, communications, operator interfaces, process interfaces, and any other interaction that may occur. Inadvertent interfacing must be considered, including such issues as electrical noise, electromagnetic interference, cutting swarf and debris, process off gassing, mechanical vibration, etc. Detailed equipment layouts and modeling will help this process (3-dimensional or solid modeling), and will help identify procurement requirements that need to be imposed on vendors.

A non-inclusive list of interface examples include:

- Ensuring that the selected conveyor system fits between the legs of the gantry
- Ensuring that the gantry is fitted with appropriate provisions for supporting bridge- and mast-mounted lighting and camera systems.
- Ensuring that the gantry is outfitted to support the mast-mounted dexterous manipulator system (it will need to be able to support the manipulator reaction loads and it will need to provide the manipulator with required services).
- It will be necessary to work out procedures and controls for avoiding unplanned contact between the gantry Cartesian manipulators and the overhead heavy lift crane, etc.

Standardization

Standardization is an important part of reducing spares, maintenance difficulty, and system integration. However, desires to standardize should not constrain the true functional need for equipment. Examples of this include:

- Pan/tilt/zoom cameras for fine motion work versus area views for avoiding unplanned physical contact between equipment.
- Deciding if a technology vendor (overhead crane or shredder vendor, for example) is to provide their standard remote vision system or just the interface so that a different vision system can be purchased and installed (one that is consistent with what will be purchased for the rest of the facility).
- Purchasing a specific brand of hydraulic manipulator to be installed on pedestals at a sorting table. A gantry is purchased and one of its “tools” is a manipulator. Is it worth the integration effort to require the vendor to use the same hydraulic manipulator on their gantry if the vendor has an electric manipulator that may meet most needs? If commonality of parts and operator interface are important, then integration work will need to be performed to mate the hydraulic manipulator to the gantry. If it is not important, then the operator controls will be different than the other manipulators. Hence more training will be required, and different control stations will be required, etc. There may, in fact, be positive aspects to utilizing the vendor’s electric manipulator over the hydraulic manipulator that drive the decision more than commonality of interfaces/parts. For example, the vendor may have an integrated control system that allows complex coordinated motions to occur utilizing the gantry and the manipulator.

There will be significant difficulty procuring equipment from different vendors that will have any commonality of parts. A decision will be necessary on whether having different equipment is more problematic than having to perform some systems integration.

On a more micro scale, for maintenance it would be ideal for most fasteners (bolts, nuts, screws, etc.) to be the same size so that a single tool could be taken into the radiation zone for repair (crane maintenance bays, for example). However, this type of commonality of parts is highly unlikely to occur across vendors.

Operations

As envisioned, the container opening cell is a complex environment. Many systems will operate simultaneously, some of them in coordination with one another and many of them having the potential to physically contact one another. Selecting and coordinating camera views and interacting with other in-cell systems (airlock doors, air balance, etc.) further add to system complexity. A great deal of careful design should be undertaken to ensure that the operators have the flexibility they need to perform their jobs, but are not overwhelmed with an excessively complex working environment.

Areas of interest include the number and type of system controllers, control of cameras, sharing control of cell-wide systems (such as cameras and conveyor systems), equipment operating envelope overlap and the resulting potential for unplanned physical contact.

In terms of controllers, manipulator vendors (as well as other equipment vendors) generally provide their own operator interface systems tailored to the device they supply. Some of these interfaces are relatively simple – a small “master” arm perhaps 12-inches in length mounted to the top of a controller box about the size of a breadbox. Other controllers are quite large and complex – a pair of 19-inch rack cabinets, each having a computer and a number of other devices installed in it. In some cases, if an operator is expected to use as few as two manipulators (together with the camera system, conveyor system and overhead gantry system), it could be physically impossible to create a usable work environment for the operator.

An alternative is to design a universal controller that is used to operate some combination of, or all in-cell systems. Each equipment vendor would then be required to adapt their system to this controller, and the operator would select which particular system to control via a switch. This may not be practical for all systems (such as force-feedback manipulators). There are also issues with the operator understanding which system will respond when a control input is provided. Ultimately, some compromise will be required to reduce the number of controllers the operator must contend with, but still allow the complete exploitation of the capabilities of each piece of equipment. A design study will be required to determine the layout of the operator control stations.

Splitting duties among multiple operators will aid in reducing operator fatigue, but may be impossible in some cases or negatively impact work flow in others. For example, if there are numerous camera systems in a work envelope, the operator may have another person help control them. But at some point, the operator will want a specific camera view, and it is difficult to adjust a camera precisely by saying "a little more to the right".

Feedback to the operator will be provided by optical (camera) and audio (microphone) systems. The cell may have dozens of camera views available to the operator, and it may not be simple to determine which views will be most useful. A system that allows the operator to readily select a desired view and to control that view (camera orientation and zoom, etc.) will be required. Some system for handling contention (demand from multiple operators for the same camera) will be required as well. Rather than rely exclusively on manually controlled cameras, it may be desirable to give some cameras the ability to track on the tool point of a given manipulator system. Thus, as the operator performs a manipulation task, the camera will continuously reposition itself to track on the task. It will also be necessary to manage the use of audio feedback. Operators may need to wear headphones to avoid disturbing one another.

Balance of Plant Scoping

Standard balance of plant considerations should be made for items such as ventilation and conduit space/routing, utilities and utility redundancy, space claims (bulkheads, pumps, breakers, etc.), e-stops (emergency stops) , hose/cable life and remote replacement, and servicing equipment (filter change outs, etc).

Consideration should also be given to the mounting location of heavy duty equipment subject to large reactive loads (backhoe boom, for example). Floor loading will need to be considered, and it may be advantageous to mount these devices between the T Plant process cells rather than to the cell cover blocks, as the cover blocks may move or shift slightly under extreme working conditions.

In addition, thought will need to be given to specific ancillary equipment, such as hydraulic power units. Many elements of the SWPC will be hydraulically operated (dexterous manipulators, heavy lift manipulators, booms, shredders, etc). A comprehensive hydraulic power system will be required. It may prove desirable to design the system to operate on two or more independent hydraulic systems – one for the dexterous manipulators, which require extremely clean fluid, and one for the other system elements (heavy lift manipulator, booms and shredders). Most of the time, demand on this system will be very low, but may become quite high with little warning. A load-sensing system operating on multiple pumps may be appropriate – additional pumps may be switched on as much as demanded of the system.

Contamination Control and Decontamination Capability

An overall contamination control and decontamination philosophy will need to be established for the design and operation of the facility. Remote decontamination will be required to keep the process modules as clean as possible. High contamination levels will affect the ability to survey, maintain, and operate equipment within the module. Good housekeeping habits will be very important.

At load-in, standard hot cell practices should be used, with airlocks with changeable door sizes to minimize openings, and ventilation flow and direction control.

Within the process cells, ventilation control will continue to be critical. Other considerations might include:

- Designing for use of partitions to reduce the area of potential contamination,
- Use of electrostatic precipitators as pre-filters for HEPAs (easier to change out)
- Strippable coatings on cell walls/floors/ceiling and containers before facility entry
- The use of the waste container as the containment boundary. A plastic tent device deployed by a fixture is attached to the container. It has slits for crane or tooling access, its own ventilation, and is disposed of with each container. This is a proven method for contamination control that is used on site today, and may be best suited for unusually hazardous containers.
- Use of trays to keep debris off the floor
- Use of oil-based fogs to minimize airborne contamination (will not stop contact contamination transfer)
- Any available decontamination technologies.

At load-out, the removal of containers from the SWPC hot cell environment will require the use of bagless transfer type concepts. Several methods are available, including those designed for 55-gallon drums. Two bagless transfer options include a "split plug" system[2], and a double door transfer system[3].

Other items that need to be considered include:

- Will tools, manipulators, etc. need to be wrapped or bagged in plastic? If so, this will affect aspects of remote vision, lighting, tool selection, approaches to tasks, and limit tool access (need larger opening if manipulator is wrapped).
- What components will be considered "disposable"?
- To what extent do decontamination efforts come into play? What equipment can be decontaminated, and what methods should be used?

[2] http://sti.srs.gov/fulltext/ms9800649/ms9800649.html, and http://sti.srs.gov/fulltext/ms200077r1/ms200077r1.html

[3] http://www.centres.com/nuclear/ddts/ddtsoper.htm

Criticality

Potential material accumulation locations within/adjacent to equipment will drive some equipment or handling requirements. A prime example of this will be the shredder. The shredder output stream will need to be sieved to collect the fines in a manner that precludes criticality configurations from occurring. The fines will need to be surveyed and stabilized in safe configurations, then directed to the packaging process in a controlled manner.

Devices such as low lipped trays (less than 1 ½ inches high) or geometrically correct vacuum systems can be used to collect and move the fines away from the shredder and into safe containment. The process may be time consuming and may affect the process throughput of the shredder.

Attention will need to be paid to how any potential liquids might collect near the fines, and what mitigation is required. If a non-flammable hydraulic fluid is used in the shredder (such as the equivalent of mineral oil), a leak from that line should not be of great concern. Theoretically there should not be any liquids at this stage of the process, but to ensure this, a requirement for opening every container to check for liquid prior to size reduction may be necessary.

Equipment Servicing, Maintenance, Planning for Upset Recovery, and Rework

Critical to sustaining the 15-year life of this facility, and maintaining the required process through put will be planning for equipment servicing, maintenance and upset recovery. All remote systems will require maintenance, repair and possibly replacement. The SWPC will need to plan for outages for the repair/replacement of critical systems. It is not uncommon for process facilities with much less complexity than the SWPC to have regularly-scheduled outages. The West Valley Remote-Handled Waste Facility endured a 2-month outage in 2005 to repair a remote gantry system.

Items that should be considered:

- Design and develop procurement specifications to minimize maintenance that is required inside the processing cell
- Design in isolated and decontaminatable service bays for the large mechanical components (cranes, gantries, manipulators, etc.)
- Develop advanced recovery designs for catastrophic failure of large components like conveyors and shredders
- Specify that large equipment be as modular as possible so that components can be replaced more easily

- Treat small, inexpensive equipment as disposable
- Utilize quick change plates where possible
- Vision system components should be mounted within enclosures that are easily decontaminated and changed remotely. Additionally camera change out should be regularly scheduled to avoid burn out of all vision components simultaneously (thus leaving you blind for camera change out)
- Complete dose rate modeling (affect of dose on equipment)

The facility should be designed to be able to reverse process. Any time there is an inspection, evaluation or test (welding inspection, radiological survey, leak test, etc.), there is a possibility of a need for process rework. Additionally, upset recovery and rework may be required because of process equipment failure, such as a jammed shredder or broken conveyor system. Consideration should be given to the failure of each piece of equipment, and the resulting waste on/in that equipment at the time of failure.

The facility will need physical space for spare parts and tools and consumables used in the installation of the parts. As an example of what space may be required, a remote system consisting of a control trailer, backhoe, heavy-duty articulated manipulator, tooling, hydraulic pump, water pump, and numerous cameras required a 20-foot shipping container (20ft x 8ft x 8ft).

Data Collection

Beyond standard data collection activities, consideration should be given to maintaining historical process/operational information. There will be a significant amount of operator turnover during the life of this plant, and capturing and communicating past knowledge and information will be extremely valuable. This might be thought of as an experience or process knowledge data base, and it could contain information such as what tools are effective on what materials, and what operational approaches have been tested (successful and not) for specific challenges.

In addition, real time collection of operator functions could be considered. This might be a system for automatic tracking of system and operator information at log-in. It could include entry of container ID, manifest information, and recording of information such as what manipulator was used to deploy what tool for what task by what operator. Information like this could then be sorted to evaluate system, process and operator performance, or to focus on the root cause of upset conditions.

Example Equipment and Individual Component Integration

For the Primary Container Opening Cell where functions of opening, sorting, and size reduction will likely take place, a basic set of example equipment is presented here for discussion purposes. This includes overhead heavy lift cranes, gantries, heavy duty articulated manipulator systems, hydraulic booms, heavy duty transport devices (conveyors/rails), cameras, and shredders. The equipment is based on a pre-conceptual design developed by reviewing preliminary inventory data and requirements. A model of the concept is shown in Figure 2. The estimated number of each piece of equipment is shown in Table 1, with a non-inclusive list of potential commercial vendors who supply like equipment.

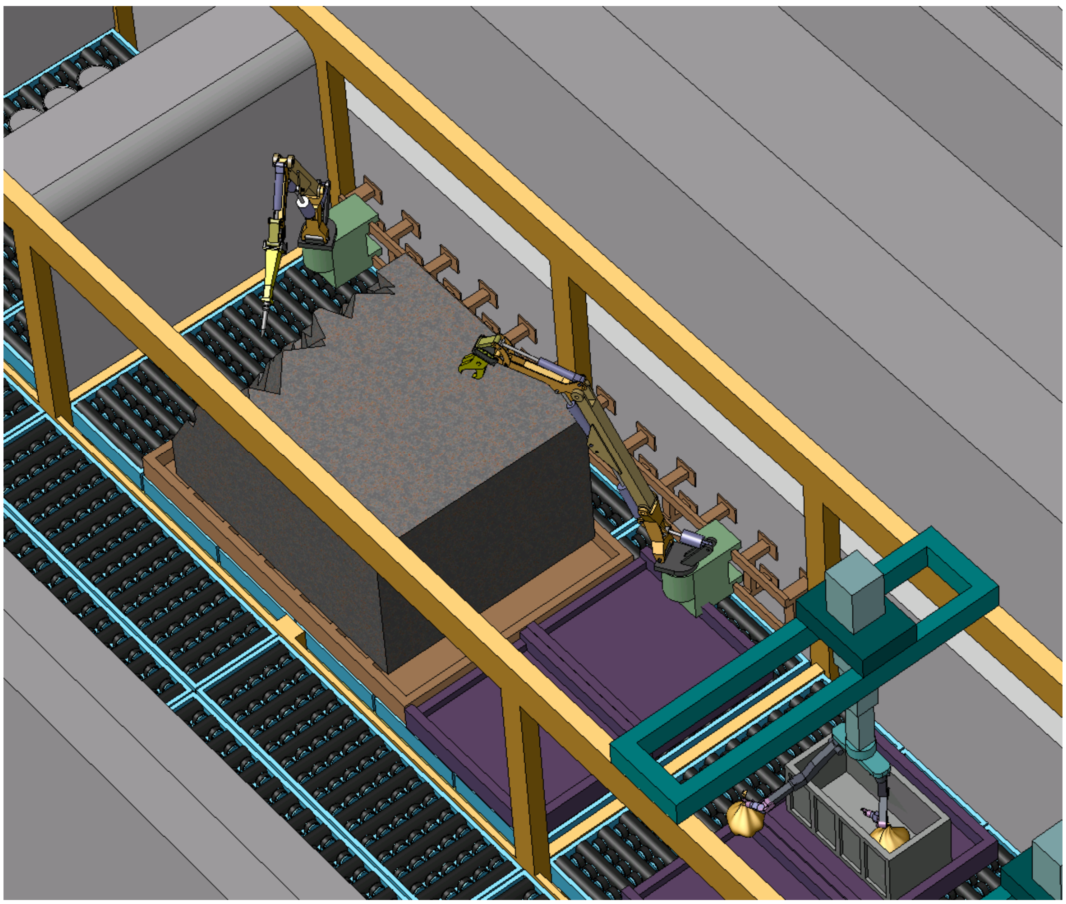

Figure 2. Pre-conceptual 3-Dimensional Model for Primary Opening Cell

Table 1. Basic Example Equipment

Equipment Type	Estimated Number	Non-Inclusive Vendor List	In-Use Location
Heavy Lift	1-3	ACECO, Ederer	1
Gantry	2	PaR Systems, BMI Automation	2,4
Heavy Duty Articulated Manipulator	4-12	Shilling, PaR Systems, Fanuc, Kraft	3,4
Transport		Automated Solutions, Inc., Conveyer & Castor	
Camera	20	*Rad Hardened:* Roper Resources Ltd, Thermo Electron Corp., IST, SIRA *Non-Rad Hardened*: Industrial Video Systems, Inc., Sony, Panasonic, etc.	1,2,3,4
Shredder	1-3	SSI	4
Hydraulic Boom	1-2	Case, Cat, John Deere, Brokk	1,3,4

Location Key:
1 = Hanford, WA – Spent Fuel Handling, Tank Farms
2 = West Valley, NY – Remote-Handled Waste Facility
3 = Oak Ridge, TN – Spallation Neutron Source Target Facility, CP-5 Program[4]
4 = Idaho Falls, ID – Security Training Facility[5], Advanced Mixed Waste Treatment Project

Heavy Lift Crane

Heavy lift cranes (see Figure 3) are available for purchase from industry. They are custom fabricated to a user-defined specification. Most heavy lift cranes are controlled by operators within line of site of the hook. For the SWPC facility, the heavy lift crane will need to be "remotized" for use via vision systems (cameras), as the operator will not be in visual contact with the system.

[4] DOE/EM-0389, Technology Summary Report, Dual Arm Work Platform Teleoperated Robotics System. Office of Environmental Management, Office of Science and Technology, U.S. Department of Energy. December 1998

[5] DOE/EM-0597, Technology Summary Report, Modified Brokk Demolition Machine with Remote Operator Console. Office of Environmental Management, Office of Science and Technology, U.S. Department of Energy. September 2001.

Figure 3. Overhead Heavy Lift
Photograph courtesy of Zinter Handling Inc

Figure 4. Overhead Heavy Lift Container Grappler
Photograph courtesy of American Crane and Equipment

Firms such as ACECO[6] advertise fully remotized nuclear grade heavy duty cranes. They also can provide custom fixturing for the crane, such as box or drum grapplers (see Figure 4).

If appropriate up-front design work is performed, the crane can be specified with services (power and communications) and mounting locations for cameras and lights, etc. The vendor may provide vision systems; however, SWPC may want to specify something different to standardize the camera systems throughout the facility.

Overhead cranes are a very mature technology that pose little technical risk. Integration of cranes into the overall system should be relatively straightforward, although some provision must be made to avoid unplanned physical contact between the overhead crane and other in-cell systems. Cranes can be built so that no single failure (rope hoist, drive wheel, etc.) can cause the load to fall or prevent it from being moved. Cranes have mandated inspection intervals that will impact equipment availability and require periodic access to the crane (this is normally done in some type of maintenance bay). There are many payloads that can only be moved by crane, but remotely rigging many payloads will be challenging.

Gantry

Gantry robots, also referred to as Cartesian robots (Figure 5), provide flexible and efficient solutions for a wide range of applications including pick and place, machine loading and unloading, stacking, unitizing, and palletizing. Gantry robots typically have three degrees of freedom (DOF) along the X, Y, and Z coordinate system. Most gantry robots allow teach and repeat motions to allow them to perform repetitive tasks efficiently. End-effectors may be designed to be interchangeable to allow the use of different tools from a single gantry robot. The use of tool change plates is encouraged when utilizing multiple tools.

Gantry robots may also be used as the base platform for deploying other manipulators. The gantry acts as a gross positioning system and the manipulator can perform the fine work. Several companies have developed combined gantry robot and manipulator systems that are used in module environments. Gantry systems may be driven electrically or hydraulically; electrically driven systems are the most common commercial systems. To return to a specific point in space, the system must have precision orientation sensors. These sensors may require special maintenance to keep them free of debris and from damage.

The main industrial application for gantries is for fixed or flexible automation tasks (hundreds to perhaps millions of identical actions, controlled by a computer in a fixed environment). These include everything from milling plugs and molds for boats[7], drilling, routing, and water jet cutting to factory assembly, box opening and palletizing[8].

[6] http://www.americancrane.com/Nuclear/nuclear.htm
[7] http://www.par.com/marine.cfm
[8] http://www.par.com/applications/Packaging/Gantry%20Palletizing.pdf

Tasks to be performed within the SWPC facility will be performed remotely and the environment is unstructured. This will require “remote systems” or “robotics” rather than automation of a repeated task.

Figure 5. Gantry
Photograph courtesy of PaR Systems, Inc.

Many companies build gantries for industrial use, and some for nuclear environments. However, for the most part the nuclear grade activities are limited to applications such as fuel handling and/or refueling, which are essentially task automation applications[9]. Use of gantries in unstructured nuclear applications is something that is done very, very infrequently. Thus, while a gantry is off the shelf technology, it requires integration and testing to make it work within the unstructured and remote SWPC environment.

The sophistication level (precision) of the gantries commercially available greatly exceeds the precision required for the SWPC facility. For many of the activities in SWPC, the gantry system will be used as a “gross positioner”, with fine movement/tasks to be completed by other pieces of equipment attached to the gantry, such as manipulators. Ideally the SWPC would like to purchase a less precise system but which is more powerful and robust (if it is available).

Though gantries are readily available products from industry, each is essentially custom-built for the specified application. The SWPC facility would likely want to specify gantries with teach and repeat capability (to perform repetitive tasks efficiently), controls to prevent equipment contact, and programmable work envelope restrictions. One or

[9] http://www.parnuclear.com/applications/Nuclear/Nuclear%20Refueling-Taiwan%20Power.pdf

more service bays, and a means to move a disabled bridge into these, will be necessary for decontamination, repair, and maintenance activities.

Once purchased, the gantry would typically be installed by the equipment vendor, including setting up the controllers and cable routing to the control room. Power would be supplied via hardwire to facility electrical panels.

Integration efforts post vendor installation would include the following:

- Manipulators (if purchased separately):
    - Interface plate/mount
    - Manipulator hydraulic power units (HPUs) outside cell, power to the HPU, hose routings from the HPU to the manipulator (crosses cell boundary)
    - Controls routing (can be specified to route with gantry) to control room, integrate with user interface.
- Controllers (hidden computers for each bridge) in the control room. Determine the user interface for the gantry. Determine control stations – number of personnel for each controller or set of controllers (perhaps a 2 person station for each bridge, each person gets one manipulator with common gantry control). Integrate control station with remote vision systems, etc
- Mast and bridge mounted camera and lights – Location, positioning, mounting, and cabling decisions (see camera section)
- Provide for utilities for tooling. These may be plumbed via the gantry mast and manipulator (part of equipment specification), or may be ancillary (thus requiring umbilical (power and controls) management)
- Possible tool rack/holster on mast (likely engineering/developmental activity), and tool user interface in the control room
- E-stops – need to define and implement.

Heavy Duty Articulated Manipulators

Heavy duty articulated manipulators and controllers are available commercially (Figure 6); however, they are not "stock" items and buyers must wait for vendors to physically fabricate the hardware. Typically the vendor will supply the hardware and a standard teleoperated control package that will need to be integrated into the larger process system and control room. In general, a standard manipulator will bolt to its mount, and tools used by the manipulator will be acquired with the gripper.

Once purchased, the manipulators will be delivered as stand alone pieces of equipment. Depending on the purchase order and vendor, HPUs may or may not be included. In addition to the vendor package, the following integration efforts will need to be undertaken:

- Develop and implement a manipulator-to-gantry quick-disconnect change out plate for remote removal and replacement of the manipulator. This mounting plate will not be strictly required for the table manipulators if they can be accessed for manually-assisted mounting/de-mounting for service and replacement. It will probably be advantageous to use a mounting interface plate similar if not identical to those used on the masts to mount the fixed-base manipulators, and to position them where they can be installed or removed using a gantry/manipulator and transported to a service bay. Potential contamination issues arise whenever these quick-disconnects are used, though fluids for the most part should be isolated.

- Develop and implement fixturing to enable the remote acquisition of a replacement manipulator. The fixture must position and hold the manipulator base such that the correct alignment and acquisition can be made with the gantry mast.

- A remote quick-disconnect tool change plate will be necessary for the gripper end of the manipulator and each of the tools to be used. This may need to be custom designed based on the desired interface between the manipulator and the tools and the operational requirements. Several vendors offer tool interface plates of varying degrees of complexity, consisting of the manipulator-mounted half and the tool half, both including electrical/control and fluids quick-disconnects. Using interface plates in place of a baseline gripper allows for simplified acquisition of tools (end effectors), one or more of which can be task-specific grippers.

- Manipulator HPUs outside cell, power to the HPU, hose routings from the HPU to the manipulator (crosses cell boundary), control cable routing from manipulators to control room, integrate with user interface, video systems, and control stations. Replacement of hydraulic hoses will be an issue, especially if they are integrated into the gantry cable tray/management system.

Figure 6. Hydraulic Manipulator
Photograph courtesy of Schilling Robotics, LLC

Hydraulic Booms

For heavy duty destruction activities (jack hammering open concrete casks, for example), one or more fixed-based boom systems would be advantageous (Figure 7). Several systems are commercially available, including some with pre-existing tooling. Boom systems are regularly used in industry – investment casting[10] is just one example.

Several vendors can provide remote controlled booms. Generally, the booms are operated from line of sight. Remote vision systems will be needed for use in the SWPC.

If not provided by vendor, remotization will include replacing typical mechanical proportional valves with electrically controlled proportional valves. It would also be necessary to develop the operator interface and control box, which in the simplest configuration would convert proportional signals from joysticks to the proper proportional signals for the valves. More complex control systems using servo valves or binary valve banks could be used with a computer controller and software development

[10] http://www.vulcangroup.com/index_equip_brands.htm

to achieve more complex motion. It is unclear whether vendors currently supply complex motion or Cartesian motion with controllers.

Although many of these booms currently have tooling assortments, development will be required to adapt the tooling for remote change out. Most boom tooling currently relies on manual intervention (someone pulling a pin to release the tool and manually making utility connections) for tool change out. If complex motion is not available, tool plate design will be somewhat challenging to allow the boom operator to acquire the tool remotely.

Some commercial equipment may require special order from the vendor to remove the mobile base platform, but still allow the shoulder range of motion required. It may be advantageous to mount this equipment to a moveable base (such as a rail), so that it can be taken into a separate bay for service.

Typical preventative maintenance includes lubricating bearings (which should be easy to remote), replacing hoses (unknown life in high radiation environment), tool replacement, and hydraulic fluid change.

Figure 7. Hydraulic Boom

Transport Systems

The conveyor/rail type transport systems required for this application (ultra heavy duty and remotely operated) are not available as off-the-shelf items. They will be custom fabricated to match the application requirements. Though this target application is not off-the-shelf, conveyor technology is mature, with possible availability of remote repair or replacement of modules, automated remote lubrication, and sensors to determine if these operations have been successfully completed. Design integration efforts to consider will include:

- Interlocks at airlock doors, assay facility doors, etc
- Lock out to prevent motion when a load is being worked on with manipulators
- Unloading to shredders
- Remote controls and vision systems
- Conveyor traps, spillage recovery or prevention
- Scales to weigh loads.

There are other transport systems that can be considered including the overhead crane, a rigid mast gantry, a remote fork lift, or a powered cart. Each of these classes of systems is at a different level of maturity and will pose different developmental, integration and maintenance issues. The following should be considered when selecting a transport system:

- Acquisition cost

- Operating labor (does it require manual operation, assisted manual operation, or is it fully automatic)

- Controls (commercial off the shelf [COTS] with product, requires software implementation, or development required)

- Degree of commercial availability (COTS, COTS with custom modification, or custom)

- Preventative maintenance required

- Disposition (can it be treated like process waste, does it require some disassembly, or is it a significant effort)

- Repair/replace effort (simple, some difficulty, or significant effort)

- Throughput (no wait time, moderate affect on flow, limiting flow factor or pinch point)

- Balance of plant requirements (needs only utilities, impacts other systems, or substantial impact on multiple systems)

- Impact on space/layout

- Contamination control issues – both airborne (cell to cell) and contact

- General versatility, work-arounds, flexibility

Cameras

Vision systems are key aspects of remote operations. Correctly located and selected cameras are essential for successful remote operations. Conventional camera views do not provide the depth of field information required for efficient remote operations. While stereoscopic vision systems can provide this information, all of the display methods available have shortcomings. A remote system of this type will require a large number of cameras, some in fixed locations and others mounted to moving elements of the systems such as the gantry and articulated manipulators. Managing the information from all of these cameras becomes a task-loading issue for the operator.

Camera systems will be COTS, but options/adaptations will be required for remote use. System design integration efforts should address:

- Automatic/manual focusing and the control parameters and technology for automatic focusing. Some systems may not work well under the lighting conditions or will tend to auto focus on whatever provides the best contrast in the field of view – not necessarily what the operator wants to focus on.

- Degree of radiation hardening required, to be weighed against predicted useful life, image quality and fully burdened replacement cost of "disposable" cameras (acquisition, installation, and disposal).

- Decisions regarding network video systems or multiple-channel analog systems. Network video systems operate with minimal cabling [Ethernet, using one of several protocols for video data and camera controls, as well as power over Ethernet transmission (POET)] but are, at present, somewhat on the leading edge and difficult to source from experienced vendors. Multiple-channel analog systems require power, controls and signal cabling connections to each camera. Technology is rapidly changing and these types of decisions will need to be addressed at a later date.

- Mounting – cameras should be accessible for replacement using the gantry/manipulator systems or other planned methods, and the mountings specified, designed, and tested to support this requirement.

- Positioning – location of cameras to provide appropriate perspectives on all operations. Determine pan-tilt mount requirement for each location.

- Zoom/telephoto/macro lens focal length.

- Cable management – power, communications, with no interference with any other equipment

- Monitors and display stations

- Controllers, switches – decide which camera views go to which monitors
- Recording capability (digital video recording)
- Possible use of 3-dimensional or stereo systems. In general, they greatly enhance operator effectiveness, reducing the potential for physical equipment damage, and acquisition time for picking up loose articles. However, most of the systems that were state-of-the-art 5-10 years ago made at least some operators ill. This has been an active area of technology development, so it would be appropriate to engage in a market survey and product evaluation in conjunction with the camera system design effort.

Lights

Strategically placed lighting will be required; the ability to move, dim, aim, and turn individual lights on and off is important. This will allow the lighting to be customized to accommodate the work flow. It is important that the operator be able to manage the lighting without distraction from the main task.

Lighting will be off the shelf, but most likely will require special fixturing to promote remote change out. Different types of lighting (i.e., LED, fiber, fluorescent, metal halide, etc.) may be advantageous for different positions within the cell (i.e., general area lighting versus specific task lighting versus visual inspection lighting). Remote change out may be more difficult depending on what type of lighting fixture is designed and where the light is located. The most difficult to change lights will most likely be high in the cell. Cases may exist where lighting needs to be on a pan/tilt mount to allow more precise positioning.   Some instances may allow the lighting fixture to be mounted outside the cell with a window or bubble inside the cell. Task lighting may need intensity control so vision systems are not blinded or to increase visual contrast. Cabling for all the lights will need to be routed out of the cell to the operator control station. This will be more difficult to accomplish for lights mounted to the heavy lift or gantry bridges.

Manipulator- or Other Remote System-Mounted Tools

One of the most difficult integration tasks required for remote size reduction and repackaging is tool selection, testing, and modification. Although most tools utilized will be COTS, they generally are not useable without modification for manipulator/remote use. In fact, each tool will require unique modification to allow the manipulator to coordinate orientation and motion of the tool effectively, to avoid applying excessive force to the tool, and to accommodate reactions of the tool to varying workpiece characteristics during the course of an operation. Even after modification, testing will show that some tools are nearly impossible to deploy remotely.

The first modification for tooling is to change the grip from a human or other machine grip to a grip suitable for a manipulator, or to add an interface plate. Several types of fixtures can be added to tools to orient the tools properly when the manipulator grips them. The most popular type of grip requires a physical handle to be applied to the tool such as a square block or a T-handle (Figure 8) that will be easy for the manipulator to grip and have some orientation control. This method requires the tool to be rugged enough to bolt on this grip fixture without breaking the tool when force is applied to it. One negative aspect of this type of grip is that utilities must be managed separately as umbilical cables/hoses. These can become tangled or snagged on various other objects in the cell and also limit the tool use to a confined area. When storing the tools, similar handling challenges exist.

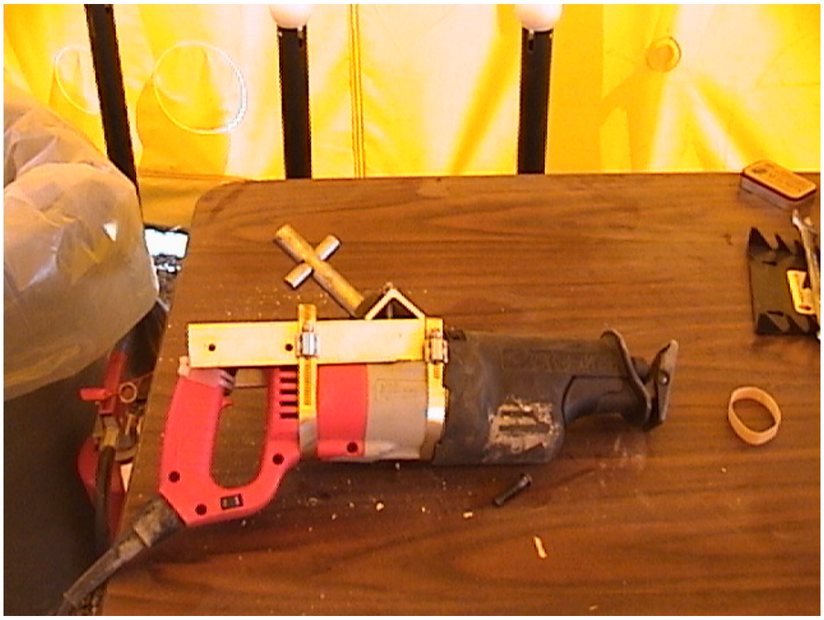

Figure 8. T-handle

The most effective type of grip fixture is a robotic tool change interface plate (Figure 9). A tool change plate consists of two mating parts (a master plate and a tool plate) that have been designed to lock together automatically. These plates generally pass utilities (e.g. electrical signals, pneumatic supply, water, etc.) from the manipulator directly to the tool so that no external umbilical is required. The master side of the tool changer mounts to a robot, computer numerical control (CNC) machine or other structure. The tool side mounts to tooling. Tool change plates require significant engineering design and integration foresight to allow flexibility in tool selection later on. For example, if the tool change plate only included electrical power, a pneumatic tool could not be used in the future without handling an umbilical hose separately. Tool change plates allow the tool to be used anywhere within the robot work envelope and are easily transportable. Because there are no external utilities to connect, tools are easier to replace remotely. Each tool change plate is also somewhat unique for each tool as not every tool will mount exactly the same way to each tool plate.

Another significant issue with modifying COTS tools for manipulator use is that the manipulator may not be able to recreate the motion required for using a particular tool. For example, a reciprocating saw is utilized by moving a blade along the cut path applying a limited amount of force in the direction of the cut, negligible force transverse to the cut, and a controlled amount of torque relative to the blade axis to effect turns. A manipulator has the capability to introduce lateral or rotational loading to the tool blade, as well as to exceed the recommended feed rate. These forces could result in binding of the blade (thereby over stressing the motor in the tool and causing tool failure), breaking the blade, or simply shortening the cutting blade life to an impractical time. Even non-contact tools can have their effectiveness limited by manipulator motion. For example, a paint gun is utilized to apply a uniform coat to a plane wall. Depending on the control system, manipulator geometry, and current location, the manipulator may not be able to create plane motion, instead making an arc (like a backhoe boom would if you simply raised the forearm) which would provide non-uniform coverage. (It should be noted however, that virtually all modern industrial painting is done by robots, which can be programmed to execute an optimized path, and to adjust speed to suit the path for uniform coverage).

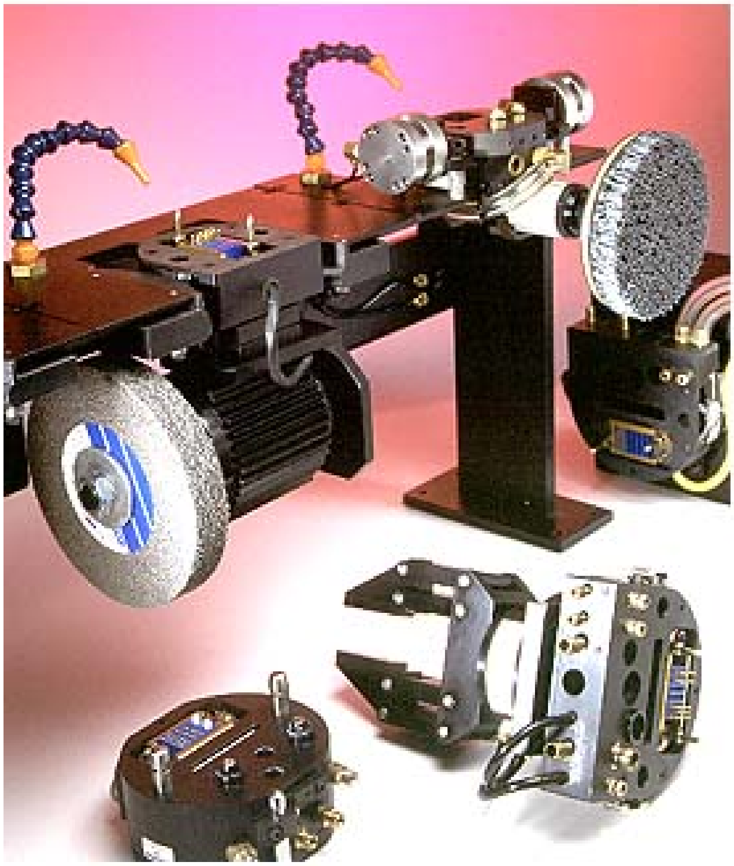

Figure 9. Remote Tool Rack and Tool Change Plates
Photograph courtesy of NASA Spinoff

Several things can be integrated into the gripping fixture to improve tool performance. Compliance can be built into the fixture such that when pushing too hard in one direction, the tool still is able to align itself properly. Tools such as a hydraulic shear could be hung from the manipulator so that gravity is the only force acting on the manipulator. Tools such as wire brushes or non-contact tools can be utilized when available which already incorporate compliance (the brush bristles) to avoid overloading the tool. Some tools (such as a jack hammer) may be better deployed from an overhead crane or backhoe type boom because the force or vibration generated may be too large for a typical manipulator to handle.

Replacing consumable parts of remote tools will also present various challenges. It may be very easy to change a portable band saw blade by hand, but remotely replacing a blade such as this may be nearly impossible. Similarly, other tools will require bits, blades, nozzles, supply gas, electrodes, etc. changed along the life of the tool. It may be more economical to treat the entire tool as a consumable or to arrange for manual servicing in a gallery instead of trying to remotely change these pieces. The effective life of some tools is often extended by the use of cutting fluids. Liquefied gases may be may be useful as such, and some effort should be made to determine the feasibility of this method.

Operator control of the tool should be kept as simple as possible. A single on/off switch for a tool is better than having several knobs and buttons that need adjustment during tool use. Although there may be instances when this is required for a particular tool, a simple operator control is generally better. It may be helpful to provide an operator control that is closely analogous to the normal controls for common hand power tools, where used. Use triggers for variable-speed reciprocating saws, for example, so the operator can translate hands-on experience to remote operation readily. Significant integration will be required to incorporate tool control into a single, simple interface if there is a large selection of tools.

An issue with these remote tools is the logic of powering them on and off. Tools powered by draped cables are connected to their power source continuously, and it is possible to (potentially inadvertently) turn them on when they are in a storage area. Other tools powered by end-of-arm services may turn on and off in different ways, because they may use different services. A relatively simple system would use a series of toggle switches to turn different tools on and off. However, this allows the operator to turn on tools that are not currently in the gripper. It also makes it difficult to distinguish between two tools that use the same end-of-arm service. Significant design work needs to be done in this area to ensure that appropriate safety interlocks are in place and that the operator can easily and accurately activate the desired tool.

Some services (such as hydraulic power) may be readily available at the gripper end of the manipulator arm. Other services (such as vacuum or electrical power as required by the plasma arc cutter) are unlikely to be available at end-of-arm. These kinds of services are often best dealt with by draping the required service lines to the tool from a wall- or ceiling-mounted fixture. While this requires the operator to manage the lines without having them damaged or interfere with the task, this is not too onerous compared to permanently routing these lines along the manipulator arm. Routing heavy, bulky lines along the manipulator reduces the range of motion and payload and adds unacceptably to the bulk of the arm.

Some kinds of tools lend themselves to remote operation. Largely, these are non-contact tools such as water jet or plasma arc cutters. These tools are tolerant of slight misalignment and do not bind up when slightly out of alignment with the cut. Contact cutting tools are, in contrast, substantially more difficult to operate remotely. Generally, tools with a long contact with the material being cut (such as rotary saws) are not tolerant of misalignment. To prevent tool failure, the tooling must be designed with compliance that can allow the tool to align itself correctly.

Alternatively, force feedback can be incorporated into the system (manipulator) to prevent misalignment. This is a challenging and not necessarily effective approach. Other types of contact cutting tools, such as reciprocating saws, share this issue but to a lesser degree.

To improve tool effectiveness, some amount of operator feedback may be desired. This may include electrical load monitoring, force feedback, or audio. Power feedback may indicate that a tool motor is overstressed or drawing high current. Force feedback can sometimes be utilized to give the operator an idea of how much force the manipulator is applying to a tool. This is generally a complex system integration task, although some manipulator vendors may have kits for purchase. Experience has shown that audio feedback is very important for rotational cutting tools such as drills, saws, and grinders. Audio allows the operator to hear if too much force is applied to a tool.

Tool storage and acquisition is another complex integration task. Each tool will require a storage location within the work envelope of the manipulator/gantry combination. Each tool must be oriented precisely when in the storage location to facilitate tool acquisition. Tools with umbilicals must avoid tangling with other tools or objects in the storage location. Tool acquisition is a difficult task to complete remotely. Most vision systems inadequately show depth which makes acquiring tools a time consuming exercise when attempted manually. However, a combination of precisely-located tools, well-engineered interfaces to the manipulator, and routine controls programming can make tool exchanges a matter of a few keystrokes and a few seconds of automated manipulator (and, where applicable, gantry) activity.

Appendix A contains a list of potential remote system tools that may be of use for the SWPC. Included are a description of how the tool works, and what types of waste items they may or may not be applicable to use on.

Additional end-effectors and tools for the manipulator or heavy lift may be required to solve tasks as they arise. For example, a portable camera and lighting system may be necessary to aid in the acquisition or identification of a waste item, or a specific waste item may prove difficult to acquire with an existing method or tool and require a specialized tool to be designed. This tool will need to be passed into the module and acquired appropriately.

Fragile items such as glass bottles or light bulbs may require force feedback or special tool development for the manipulators. Special tooling must limit the force applied to an object. An example of this type of tool would be a grappler with flexible fingers. If more than the minimally required force is applied, the fingers will bend yet maintain a grip on the object.

Fixturing or Automation Station Possibilities

Certain tasks may lend themselves to performance by single-purpose machines with limited operator interaction. The most prominent example of this would be systems for container opening. This type of fixed automation would apply when many containers of essentially the same type are found in the waste stream. Paint cans, 5 gallon buckets, and 55 gallon drums, for example are all found in large numbers in the inventory. Holding these types of containers in place with one manipulator arm (or a static fixture) and removing the lid with the other manipulator will be a challenging task. A single-purpose machine that automatically grasps the container, removes the lid, and presents the opened container and lid to the manipulator would save a great deal of operator time. The key is that there needs to be a relatively large number of the containers in question and they need to be of substantially similar design (construction materials, dimensions, lid securing method, etc.). There is a variety of COTS equipment available for activities such as opening a 55-gallon drum.

Fixtures will prove useful for other tasks as well. Some type of fixture to aid in opening plastic bags will be useful, and it may be helpful to have tools to help deal with containers of liquids. Certain waste forms (such as lead bricks) may occur frequently enough that a tool to automatically stack and package them would be of value.

Considerable design, development and testing work will need to be performed to create fixed automation tools that will reliably perform the required tasks. An understanding of the inventory must include the designs of all of the containers, especially how the lids are secured. Different styles of drums may require different machines to open them or an adaptable machine that can handle a variety of geometries. The same is true of boxes and paint cans. Successful deployment of container opening machines will demand an extensive testing and development program.

One down side to fixtures or stations is that they take up real estate. This can be helped by fold down designs, and positioning fixtures in areas outside the prime work space for manipulators, etc.

Shredder

Ultra heavy duty shredders are found regularly in industry (Figure 10). At least one vendor[11] has built five or six inert environment shredders, though not for a radioactive environment. Any shredders purchased for the SWPC will be custom designed and built based on the user’s specification. They will need remote control and vision (if not included). Interfaces will be needed with the incoming waste transport method (conveyor, lift, etc.) and with the outgoing containerization process, which may be inside the equivalent of a bagless transfer system. The infeed will require a hydraulic ram, which most vendors already have developed. For the SWPC application, design efforts

[11] http://www.ssiworld.com/applications/applications8-en.htm

will need to focus on controlling the gas purge system because the vented gas will probably be contaminated.

Significant effort will be required to design the shredder to survive the 15 year lifetime of the plant with minimal maintenance. The more information available regarding the material to be shredded will help this effort. General preventative maintenance includes lubricating moving parts, replacing worn bearings, replacing cutting teeth (Figure 11), and even replacing shafts. If a hydraulic system is used, the fluid will require change out. Typically, cutter life is estimated at about 35,000 cubic meters. Remote cutter or shaft change out has not been attempted yet by vendors, and would be a unique design feature.

Figure 10. Shredder
Photograph courtesy of SSI Shredding Systems, Inc.

The drive motors should be outside the cell to the extent possible, which will ease lubrication and maintenance on a failed unit. The infeed and discharge areas will need to be monitored by video so protected locations will be needed for cameras and lighting.

Decontamination features and methods should be integrated into the equipment design and/or installation in close collaboration with the vendor. These features might include:

- Spraying the equipment with CO_2 ice
- Bead blasting (recovering the media for re-use)
- Processing materials selected for scrubbing efficacy and known contamination properties. These could be material that is expected to be over the TRU threshold anyway or material having very low contamination that is expected to assay below the TRU threshold after cleaning the shredder.

Shredder size and configuration relies greatly on what is being shredded and what container it has to fit in upon exit. Some thought might be given to using different shredders for different materials – for example using a different shredder with different cutters for metal and concrete than would be used for most of the rest of the inventory. This might extend the life cycle of the equipment. Also, multi-stage shredding may be required to size reduce very large items. Most primary shredders will reduce items to strips 3 inches wide by up to 12 inches long.

Figure 11. Shredder Teeth
Photograph courtesy of SSI Shredding Systems, Inc.

For the most part, the largest shredders will handle a 6ft x 6ft x 6ft box full of material. The largest of the SWPC containers will need some pre-shredder size reduction, because a standard 4ft x 4ft x 8ft box will likely give the shredder some trouble. It is possible that a larger shredder could be designed and fabricated by an experienced vendor.

Consideration will need to be given on how to identify and handle unshreddable items. Unshreddable items will need to be presorted and placed in a bypass line, or if they require size reduction, be sent to something like a plasma cutter station. Items that will not be shreddable will likely include tool steel (something as solid as a 12-inch Craftsman crescent wrench may not shreddable).

For retrieval of unshreddable items that have mistakenly made their way into the shredder, the SWPC will need some kind of gripper/grabber attached to an arm of some sort.

Equipment Risk/Consequence

Most of the equipment that is at least partially commercially available will have a low probability of failure. However, maintenance will be required and failures will occur. To try and assess the risk and consequence of unexpected equipment failure, Table 2 has been developed. In Table 2, equipment failure has been defined in a number of ways: complete shut down of operations, partial failures that slow operations, equipment misuse, and radiation related failures.

Categorizing risk and consequences, and whether to repair or replace items will greatly depend on the challenges encountered, radiation and contamination levels in the cell, how long equipment has been in use, the ability to pull the unit into a maintenance bay, and commonality of parts. In some instances, remote repair will be less expensive and faster than a complete remote replacement effort, especially if it involves a large piece of complex and integrated equipment.

The failures in Table 2 are rated by categories such as capital and replacement parts cost, schedule penalties, repair/replacement effort, degree of preventative maintenance required (function of equipment availability), and if the equipment can be considered disposable. While numbers or guarantees cannot be placed on anything, at the very high level, this table can provide some insight into the facility operations.

In looking at the table the more likely failures may come from the gantry, manipulators, and cameras. The gantry issues are commonly a result of operator misuse. The manipulators may suffer from parts replacement needs (most likely caused by particulates in the hydraulic fluid if it is not kept in pristine condition). Cameras will fail regardless of whether they are radiation hardened or not over the long life of this facility.

What is important to gleam from the data is that if the gantry is damaged, it will be very expensive and time consuming to repair. In terms of the facility, it would be considered a critical component – one that will significantly affect or even stop operation if it is not functional. In terms of the manipulator, while a parts replacement may be necessary, the cost of the parts will be low, and the repair time will be low. The manipulator would likely operate in a critical flow path/operation, but would also operate with other manipulators that could pick up the slack. In terms of the cameras, there will be a lot of redundancy, so one failure will not significantly affect operations (unless it is a camera mounted to the end of mast, for example). Replacement cost, schedule, and effort will all be low or very low.

Information from tables like this should lead to design efforts that place service bays within easy distance of gantries, every effort should be made to make service as easy as possible, redundancy should be built in, and operator training should focus on preventing system abuse. For hydraulic manipulators, significant attention needs to be paid to fluid cleanliness, and for camera systems, designing for quick remote change out will be important.

Generically, one of the most important things to plan for is system outages. Recent experience at the West Valley Remote-Handled Waste Facility showed that a 2-month facility outage was required to repair a remote gantry/manipulator combination.[12]

Equipment Availability

Operational availability numbers for specific pieces of equipment are very difficult to determine. In addition to the fact that it will be difficult to get failure numbers from vendors, it will also be difficult to define actual operational hours for equipment. For example, the shredder may be rated to handle more waste in 1 day than the entire plant will process in 1 year. Will there be maintenance issues associated with NOT using equipment as often as it is designed for? As another example, it will be hard to figure out how often the manipulators will be used, and this will lead to uncertainty in preventative maintenance (and thus availability). Will they be used 4 hours per day every day, or 8 hours once a week? In this example, and using vendor-supplied information (significant servicing of the manipulator at 2000 hrs, essentially a complete dismantlement of the manipulator), several operational availability numbers can be calculated:

- At 4 hrs/day, 5 days/week for 15 years that means 15,600 hours of operation – so a complete servicing would be required a minimum of 7 or 8 times during the life of the facility.

- At 8 hrs/week for 15 years that means 6240 hours of operation – so a complete servicing would be required a minimum of 3 times during the life of the facility.

[12] http://www.wvnsco.com/wvdpinsite/Feb_11_2006_WVDP_InSite_This_Week.pdf

Table 2. Remote Equipment Failure Risk/Consequence

	Gantry	Heavy Lift	Manipulators	Transport	Shredder	Hydr Boom	Cameras
Risk of Unexpected Failure by type:							
Complete failure	Low	Low	Low	Low	Low	Low	Medium
Partial failure/slows operation	Low	Low	Medium	Low	Low	Low	Low
Misuse	Medium	Low	Low	Low	Low	Low	Low
Radiation related	Low	Low	Low	Low	Low	Low	Medium
$ Cost of complete failure (capital)	Very High	High	Low	Low	Medium	Low	Very Low
$ Cost of partial failure (parts)	Low	Medium	Low	Low	Low	Low	Low
Schedule penalty of complete failure	Very High	High	Low	Medium	Very High	Low	Low
Schedule penalty of partial failure	Medium	Medium	Low	Low	Medium	Low	Low
Repair/replace effort	Very High	Very High	Medium	High	Very High	High	Low
Required preventative maintenance	High	High	Low	Low	Low	Low	None
Can equipment be treated as disposable?	No	No	Yes	Yes	No	Yes	Yes

System Integration

In addition to the individual component integration efforts outlined in earlier sections, there will be whole system integration efforts required. This will include how individual components interact with each other as well as the waste containers and waste being processed.

Examples of this include:

- Interaction of crane and gantry bridges to ensure safe operation
- Software interlocks (timing of door openings/closings, timing of valve openings, etc.)
- Interlocks for conveyors to position containers under work stations
- Transfer of containers/waste items to different work stations
- Equipment flow/interactions for safe operations
- Work envelopes, contact avoidance – while work envelopes (gantry, tooling, manipulators, etc.) are defined in the design, equipment specification, and installation process, the moment something is introduced to the work space (waste box, for example), envelopes need to be reassessed. It is understanding the point of interaction of equipment to the waste (which is undefined and unstructured). There are also dedicated equipment work spaces that cross over into other work spaces that need to be evaluated (multiple gantries, overhead crane in gantry space, etc.)
- E-stops. If determined to be necessary, it will probably constitute a significant design effort. Which systems will be protected by it and how; where will the e-stops be located, etc.
- Handling upset conditions or rework (back flow in the facility)
- How to contain box contents during processing activities
- Interaction of partitions to other process equipment (if used to contain debris for destruction).

Cold Mock Up

A comprehensive system mock up will be required for testing the entire integrated system, selection and testing of individual tools, operator training, and task/operational planning. The mock up should be established prior to construction of the facility, and should remain in use for the entire life of the facility. During operation of the plant, the cold mock up facility will become indispensable for handling operator turnover, upset recovery, updated task planning, and new tool/technology testing and evaluation.

Preliminary mock ups of individual tools and workstations can be developed separately (and should occur very early in the design process), but eventually these should be melded into the long-term mock up. It will be necessary to perform the entire size reduction and repackaging process on waste surrogates in the mock up facility prior to doing any ‘hot’ work in the SWPC.

The mock up facility will have a number of requirements above and beyond those of the completed process facility. In addition to being a relatively high fidelity simulacrum of the process facility, the mock up will require additional flexibility. It will be necessary to temporarily reconfigure the mock up to allow for testing of candidate systems and tools. The mock up will also require a substantial safety program, because there will be personnel access to all areas of the mock up. While the operating area of the final process facility will be essentially off-limits to staff, all areas of the mock up will be accessible for the purposes of directly observing tests, delivering and removing surrogate waste articles, configuring the facility for testing, etc.

During the operation of the SWPC, the mock up facility will become indispensable for things like recovery of upset conditions (potential paths forward can be tested prior to hot work), and scrubbing potential procedures for work in the SWPC. In addition, in a facility that operates for 15 years, there are going to be equipment operators that come and go, tools and equipment that will change, new technology will be discovered, and approaches to challenges will change with processing experience. All of these things will necessitate a working cold mock up while the full facility is in operation.

The cold mock up design will require flexibility in regards to the ability to control equipment during tests. The cold mock up will physically need to be able to accommodate the different stages of controls-related activities within the mock up, and to be able to freely move from one mode to another in the mock up. Testing modes will include:

- Operator having line of site visual and audio available for system testing. In general this type of testing will be used until the team is satisfied with equipment setup and operation.

- Operator having line of site visual, and audio available, with the addition of movement of surrogate waste through the system using all tools and facility equipment (conveyors, manipulators, etc.).

- Full remote operation. Isolated equipment controls location where there is nothing but remote vision and audio feedback. Full movement of surrogate waste through the system using all tools and facility equipment (conveyors, manipulators, etc.).

The cold mock up facility will have different emergency stop requirements from those of the operational plant. Normally, emergency stops are located to protect human health and safety. Because operators may have more “hands-on” involvement with operation of the test facility, there may be greater need for a system-wide (or subsystem) e-stop. It is important to keep the e-stop system simple – it is not reasonable to expect the operator to rapidly choose which of a half-dozen e-stop buttons is the correct one in an emergency situation. A thorough understanding of both the operational and cold test facilities and their operating procedures will be required to develop an appropriate emergency stop system. It may be that only a few e-stop systems would be required for a few specific subsystems or that some type of system-wide e-stop would be required. Some tools and subsystems may require substantial engineering to accommodate an e-stop circuit.

Additional items to consider related to mock up facilities:

- Physical layout for given facility – overhead lift, access into and out of (size of roll up doors, for example), utilities, walls, floor capacity (83,000 pound box), floor space, overhead space, etc.

- Required building modifications – utility upgrades, etc.

- Required infrastructure – transport waste surrogate containers in, transport processed waste out to dump, forklifts, etc.

- Safety equipment – light fences, fire extinguishers, plexi/safety shields for destruction activities, etc., administrative controls, training levels, operating procedures, safety plans, inspections, restricted access, etc.

- Personal Protective Equipment (PPE) – safety glasses, welding glasses, etc.

- Fire suppression – both facility as a whole, and at test source

- Hot work procedures, permits

- Noise protection, procedures, permits

- Ventilation, off gas control, permits for release, ability to control atmosphere

- Hazardous material storage and controls (fuels, flam cabinets, Material Safety Data Sheets (MSDS's), etc.)
- Supplying test articles – boxes, simulated waste, tracers, drums, casks
- Handling volume of test articles – there will be hundreds of containers used
- Waste control/management – disposition of test articles post processing
- Spare tools, parts, and consumables
- Equipment upkeep – fluid analysis, filter changes, preventative maintenance, scheduled and controlled
- Incorporate ability for incident reconstruction – time stamped digital video recordings of all operations to allow for reconstruction of events/accidents during testing/training in the mock up as well as and live operations at T Plant.
- Welding and machining capability on site – support activity – on the spot ability to fab/modify components
- Personnel to maintain, operate, and control facility – identify number and type of people (engineer, technician, etc.), and required levels of training. Consideration applies to both the mock up facility and the SWPC.
- Air balance work completed in mock up will likely not be representative of T Plant operations

Testing and Operational Approaches

In addition to testing all system functionality, operational approaches for processing waste in the SWPC will need to be developed. These might include:

- Developing operational approaches and methods to given problem sets (potential classes or groups of waste streams)
- Operational fine tuning – work out details such as:
  - When the jack hammer is used all the camera shake
  - Too much reflective glare for the cameras from lights shining on stainless steel components
- What coordinated motions/tasks can be completed
- How many operations can be going on at the same time in the SWPC, and at what point do operations affect one another
- Process planning – determining the maximum number of trays to be allowed in the opening cell to facilitate any possible re-work (unexpected return of items already passed through cell).
- Determine where unanticipated bottlenecks are in the process flow and how to mitigate them
- Determine appropriate actions to facilitate recovery from upset conditions
- Equipment replacement strategies and approaches
- Dry runs for process flow, physical interference, cross-talk, electronics cooling, network bandwidth, camera controllers, recording capabilities, choke points.
- Multiple operator communication and coordination
- Camera views for all potential activities within the cells
- Lighting for all potential activities within the cells
- Determine most effective methods for keeping the cell floor clean
- Tray management
- Tool selection, adaptation, and testing

- Ability to inert the inside of a waste box
- Tool acquisition
- Fixed automation stations
- Contamination control of equipment – bagging, boots, decontamination methods, etc.

Procurement Strategies

In reviewing the requirements and understanding the marketplace, a procurement strategy can be developed to most effectively purchase or manufacture the best equipment for the SWPC. Procurement strategies should be planned well in advance, and consideration should be given to the following:

- Piece by piece procurement versus a large quantity of equipment from a few vendors.

- Cost-only versus performance specifications. Some equipment will be well suited for a cost-only evaluation (standard industrial equipment) while others will definitely require performance specifications with technical evaluation criteria. Performance specifications can effectively protect the buyer from low bid garage shops, and other vendors without the proper experience or technical expertise. Technical specifications also allow the buyer to leverage the expertise of a vendor by allowing the vendor to solve the problem to the best of their ability and experience (rather than the buyer specifying a solution).

- Develop high quality and comprehensive technical specifications based on requirements that can be tested and evaluated.

- Decisions will need to be made regarding buying versus building. What pieces/components will be appropriate for on-site fabrication in lieu of adding scope to a specific vendor? An example might be the fabrication of pedestals for pedestal-mounted manipulators.

- Decisions will also have to be made regarding service contracts, maintenance agreements, training contracts, technical assistance, warrantees, installation, shipping, spare parts, etc., for each piece of equipment and vendor.

- Technology obsolescence – Over the 15-year life of the facility there will be a very large potential for technology obsolescence. This is particularly relevant to computers, software, controllers, cameras, recording capability, data storage, etc. To combat this, does the SWPC purchase 15 years worth of spares for critical items? It will be entirely possible that key items will not be available for purchase after 3 to 5 years.

Appendix A: Potential Tooling

Potential Tooling

This appendix presents information on potential tooling that may be used for container opening, material removal and sorting, and size reduction functions within the SWPC.

Container Opening Tools (non-fixed automation)

Concrete Saw – A concrete saw is a power cutting tool used for cutting concrete or asphalt. The cutting blade generally generates a significant amount of heat that requires cooling. Concrete cutters also generally require large engines to power the tool and generate a large amount of dust if used dry. A concrete saw may be useful to open concrete casks or tanks.

Plasma Torch – A plasma torch uses a high voltage/current electric field between the head and the work piece to heat a fill gas (such as nitrogen). The ionized gas (plasma) is then forced through a vortex generator. The gas is then forced out of the generator at high speed. The plasma eats through most electrically conductive materials rapidly. The high speed of the ejected plasma blows the molten fragments of the target out of the way of the cutting jet. In addition to container opening, plasma torches may be used for size reduction. Waste items from the inventory that may be successfully size-reduced using a plasma torch include:

- Long, hollow metallic objects such as jumpers, pipes, ducting, well casings, flanges, telescoping pipes, coil assemblies, tube bundles, and conductivity probes
- Metallic ducting
- Metal waste boxes and other metal containers
- Steel liners
- Process vessels, dissolvers, condensers, feed waste containers
- Metal plates.

Plasma torches are capable of quickly cutting though very thick metals. However, plasma torches are limited to conductive materials. This mature technology approach is similar to laser cutting. An operator can select the best way to size-reduce individual items. A plasma torch may allow for separation of CH-TRU, RH-TRU, and MLLW by selective cutting. Using a plasma torch remotely requires a manipulator and a trained and dedicated operator. Commercial systems, including positioners, are available. Plasma cutting is not applicable to all waste types and requires treatment of fumes and off gases. Control of metal splatter must also be taken into account when using the plasma torch. Limitations of this technology include the consumable torch head, precise positioning between the head and the work piece, grounding the head to the work piece, and the high electromagnetic field generated by the process. Plasma torches cannot be used around combustible material unless the atmosphere is inert.

Jack hammer – A jack hammer is a portable, percussive type drill that uses a jabbing motion (much like a hammer and chisel) to break up material, especially those that are brittle materials that break apart easily. Jack hammers rely on the inertia of the tool mass to break apart the material. Typically, this requires the tool to be operated in a vertical orientation such that gravity is aiding the tool motion. Jack hammers can be pneumatic, hydraulic, or electric powered. Commercial systems are available and have been for use on demolition equipment such as backhoes. Disadvantages of this tool include the use only on brittle materials such as concrete, the amount of dust and debris generated, and the fierce vibration that must be endured by the tool holder.

Blade/Knife – A blade or knife may be used to open plastic bags found in waste containers. The blade may be fixed while the material is moved past the blade or the material may be held and the blade may be moved through the material. Orientation of this tool is critical to efficiently open the bags. The blade will require periodic replacement.

Abrasive Wheel – An abrasive wheel mounted on a manipulator is a proven technology for opening containers made of metals and some other materials. Abrasive wheels have been deployed remotely. Decontamination and maintenance of the tool may be difficult. The potential for airborne materials and contamination spread is great because of the high velocity of the blade. An abrasive wheel can be slow in operation and is not suitable for flammable materials. Associated equipment to hold the cutting tool and waste item may be complex.

In addition to container opening tasks, an abrasive wheel can be used for size reduction. Waste items from the inventory that may be successfully size-reduced using an abrasive wheel include:

- Jumpers, pipes, ducting, well casings, flanges, telescoping pipes, coil assemblies, tube bundles, conductivity probes

- Process vessels, dissolvers, condensers, feed waste containers.

Reciprocating Saw – A reciprocating saw could also be mounted to a manipulator or other positioning system to open containers. These are commonly used for cutting operation, and the initial cost of the equipment is low. A reciprocating saw can be difficult to operate using a remote manipulator, and it is not appropriate for all waste streams. It would not be suited for items with thick cross sections. Maintenance is an issue, depending on the material being cut. Frequent blade changing poses unique challenges.

Other Container Opening Tools – Opening of small or lightweight containers may require the development of a holding station that consists of several “arms” to grip a container as it is being opened. Containers the size of a 55-gallon drum or smaller will almost certainly require this to avoid tipping the container as an operator tries to open the container with a manipulator and tools.

Material Removal and Sorting

The primary method of material removal and sorting will be use of the manipulator grippers, heavy lift hook, and clamshells. Grippers are good for picking up most items less than 200 pounds that are not fragile. Fragile items may require special tooling or force feedback, a technology that allows operators to gauge how tightly an object is grasped. Hooks deployed by the heavy lift are efficient for removing objects with lifting bails, such as jumpers, or other items with bail-like features. Some heavy items may need rigging applied by the manipulator prior to lift. Rigging may be difficult to accomplish remotely. Clamshells are robust technology for bulk items, such as piles of scrap metal or piles of bolts. Clamshell jaws are typically hydraulic or electric powered.

All of these technologies are fairly robust and effective when performed remotely, although none are high-throughput technologies because it is time-consuming to acquire items. Remote vision is a key enabling system for acquiring objects by one of these methods. Camera systems generally require the user to view multiple output from cameras from different views to ensure that an object has been grasped firmly. Acquiring objects is much easier if an operator can view the equipment operation through a window.

Small loose material such as dirt may best be captured by scooping, sweeping, or vacuuming. Liquids may also be captured in this method by first applying an absorbent to the liquid. Care must be taken when capturing liquids to avoid mixing non-compatible fluids. Scoops are best used when the material is clumped together or near a wall. Scooping is a difficult task to accomplish remotely because of the complex motion required to scoop material effectively. Scooping also presents a contamination risk and possible criticality risk.

Sweepers are slightly easier to use remotely because the bristles provide some compliance. However, this task also requires a fair amount of practice to effectively acquire material. Sweeping will also require the positioning of a bin to collect the loose material. This bin must either be weighted or positioned such that it cannot be knocked over or moved while material is swept into it. Sweeping presents a contamination risk and possible criticality risk.

Vacuums are the easiest of these technologies and therefore require the least precision to acquire material. Numerous vacuuming technologies exist, including bagless and filterless vacuums that may be readily adaptable to a remote environment. Vacuuming does, however, present several hazards, including possible criticality because of the accumulation of material in the receptacle or filter media used with the system.

Electromagnets may be useful to remove and sort ferrous materials.

Size-Reduction Tools

These technologies range from very complex, expensive systems to simple industrial tools. Each has advantages and disadvantages depending on the application. Most of these tools are applicable to the anticipated inventory.

Shears -- Shears are used to cut long-length items into shorter, more manageable pieces. Industrial shears are simple and robust in design, and can be procured to handle very large components. Shears, usually hydraulically powered, generate local pressures in the material being cut greater than the ultimate strength of the material. The material being cut plastically deforms along the blade of the shear. The process is mechanical and the resulting thermal generation and airborne particulates are quite low. Care must be taken when performing shearing operations because the material being cut also elastically deforms. Once the shearing process is finished, the elastically deformed material may spring back to its original form. Hydraulic shears require a HPU.

Limitations of the shearing process are the robust fixturing required to hold the material being sheared, the hydraulic requirements (pressures range from 3,000 to >10,000 psi), and blade life. The shear blades must be periodically replaced, which would be difficult should they become contaminated.

Waste items from the inventory that may be successfully size-reduced using shears include:

- Long, hollow objects such as jumpers, pipes, ducting, well casings, flanges, telescoping pipes, coil assemblies, tube bundles, and conductivity probes, which may then be post-processed using an industrial shredder.

Disassembly -- Disassembly is another method for size reduction that may be used regularly. The manipulators within the module may use specially adapted hand tools to size-reduce large items. For example, a collection of screwdrivers, sockets, and wrenches may be used by the manipulators to disconnect an electric motor from a pump assembly, allowing the pump assembly to be size-reduced in the shredder, while the electric motor can be placed directly in the waste container because it is too dense for a typical industrial shredder. Other items that may require disassembly include:

- Centrifuges
- Agitators
- Pump assemblies
- Other motor/equipment combinations.

Baler -- A baler is essentially a trash compactor for metal salvage operations. Material is fed into a hopper and the baler compresses the materials into a relatively dense cube or cylinder. Compacted waste streams would not require other processing. Handling requirements for feeding are minimal, and packing density is relatively high for metallic components. A baler may not work well for springy, low-density materials such as plastics and paper. A baler will not work on thick-walled materials. Decontamination of a baler may be difficult; however, balers are proven technology operating in a number of salvage yards and recycling centers.

Waste items from the inventory that may be successfully size-reduced using a baler include:

- Long, hollow metallic objects such as jumpers, pipes, ducting, well casings, flanges, telescoping pipes, coil assemblies, tube bundles, and conductivity probes

- Paint cans

- Process vessels, dissolvers, condensers, feed waste containers, or other large metallic vessels.

Crusher – A crusher can be used for items such as concrete boxes or other items that can be crushed to rubble or flattened. Crushers are simple in design, and adaptable for easy decontamination and maintenance. Crushers may not work well for springy, low-density materials such as plastics and paper. Crushers and balers handle similar waste items.

Waste items from the inventory that may be successfully sized reduced using a crusher include:

- Concrete casks
- Concrete encased ducting
- Concrete tank with steel liner.

Band Saw -- A horizontal or vertical fixed-location band saw is a proven technology for size reduction of metals and other materials. A band saw can be used on very thick cross sections and is extremely reliable. Binding of the blade may be problematic for size reduction of some components. Industrial band saws can be operated with or without a cutting fluid/coolant. Computer-controlled material positioning and cutting operations are available in standard saws. Low band speed can reduce the potential for airborne contamination; decontamination and maintenance may be difficult. Band saws and shears handle similar waste items.

Waste items from the inventory that may be successfully size-reduced using a band saw include:

- Long, hollow metallic objects
- Metallic ducting
- Metal lathes.

Appendix B: Advanced Mixed Waste Treatment Project Anecdotal Information

Advanced Mixed Waste Treatment Project Anecdotal Information

The Advance Mixed Waste Handling Facility (AMWHF) has been in operation for a little over 1 year, and was designed and built at a cost of approximately $650 million. It runs 24/7/365 with a continuous influx of operators that basically hot bunk. When one operator gets fatigued, another replaces him/her and he/she goes on break or goes home. Facility throughput is estimated at about 8000 cubic meters per year. The AMWHF handles only alpha contaminated, contact-handled waste. The facility is limited to receiving standard sized wood boxes and metal 55-gallon drums.

Each container is X-rayed before it is allowed into the facility, and any container too shielded to see the equivalent of a light bulb filament inside the container is not allowed in. The facility then manually uses a PaR gantry with a giant cut off saw to open the lids. The gantry is manually controlled because the operators have found that their “standard” 4ft x 4ft x 8ft wood boxes are in fact, all different sizes and shapes. After the box is open, all the contents are dropped onto a tray for sorting, sifting, size reduction by Brokks, or if they are drums, they might be taken to a manual mechanical master slave manipulator (MSM) station for more dexterous cleanout. An additional PaR gantry is used for pick and place tasks. The boxes are shredded and the drums are compacted.

Operational feedback indicates that the Brokks may present serious maintenance issues if personnel cannot get their hands on them at all or very often. The AMWHF makes between 3 and 5 cell entries per week for decontamination and equipment maintenance. Most of those entries per week are related to the Brokks, to clean up leak points that are collecting contamination, replacing O-rings that have ruptured, and other nuisance maintenance. The facility regularly plans outages, such as the one scheduled for March 2006, where they will shut down for 4 days to make 12 entries (between 3 and 4 hours each) to repair the three Brokks in the cell. It is reported that the demolition work (mostly jack hammering waste items) that they do with the Brokks generates a significant amount of dust and airborne.

The AMWHF has been generally pleased with the PaR systems and have not had any major downtime. The pick and place PaR system is maintenance free so far. The larger PaR with the cut off saw has given them some challenges, but the problems are related to the Class I Div I Facility requirement. The special positive gas purge system and special tool plate required by that have been problematic. There have been two fires, neither of which caught waste on fire. The first one happened when the dust being collected from the cut off saw plugged the vacuum hose and ignited. The second one happened when someone left a mop in the cell after a decontamination entry and sparks from the cut off saw landed on the mop and ignited it. The AMWHF is now in the process of declassifying the facility to eliminate of the Class I Div I rating, which would allow them to go to a commercially available tool plate for the cut off saw.

The shredder works well and three wooden 4ft x 4ft x 8ft boxes can be placed in the hopper at one time.