ROCKY FLATS CLOSURE LEGACY

TECHNOLOGY DEPLOYMENT

THE MOST SUITABLE TECHNOLOGY FOR A GIVEN TECHNICAL PROBLEM WAS NOT ALWAYS APPARENT FROM THE OUTSET. PLASMA ARC CUTTING AND CERIUM NITRATE CLEANING WERE EFFECTIVE. PUSPS WAS DIFFICULT TO MAINTAIN AND OPERATE. IN EACH CASE, A TECHNOLOGY WAS APPLIED IN RESPONSE TO A SPECIFIC TECHNICAL CHALLENGE.

TECHNOLOGY DEPLOYMENT

INTRODUCTION

An essential part of the Rocky Flats Closure Project strategy was that productivity would improve as the project progressed. The commitment to a 2006 completion within the funding limits made in 1997 required 12% efficiency improvement per year. Executing a strategy to deliver that level of continuous improvement required identifying and deploying many innovative processes and technologies. Which technologies proved the most beneficial depended upon the project characteristics and scope. Principle characteristics of the Rocky Flats Closure Project were the types and location of the contaminants, the relatively large decommissioning component, and the need to ship all wastes offsite for disposal. Specific philosophies for the deployment of technologies included establishing the conditions that allowed the work methods to evolve, and identifying specific problems that needed resolution for the overall Closure Project to succeed. The accurate definition of the overall closure scope and development of a project baseline, including assigning project risk by activity, supported the evaluation of prospective technologies. The process used to target activities where new technologies could be effectively employed, as well as examples of the new technologies deployed, may be useful in the planning of other Closure Projects.

ACCELERATED CLOSURE CONCEPT
CONGRESSIONAL SUPPORT
REGULATORY FRAMEWORK
CONTRACT APPROACH
PROJECTIZATION

SAFETY INTEGRATION
SPECIAL NUCLEAR MATERIAL
DECOMMISSIONING
WASTE DISPOSITION
ENVIRONMENTAL RESTORATION
SECURITY RECONFIGURATION
TECHNOLOGY DEPLOYMENT
END STATE AND STEWARDSHIP
FEDERAL WORKFORCE
STAKEHOLDER INVOLVEMENT

Six topic areas include descriptions of technologies that directly supported the improvement in Closure Project cleanup efficiency:

Waste Packaging Innovation addresses methods to characterize and package wastes generated by the decommissioning of radioactive process equipment, which helped streamline the entire process from decommissioning through disposal, and substantially reduced overall Closure Project costs.

Glovebox and Tank Decontamination identifies methods used to decontaminate highly contaminated pieces of equipment, resulting in the minimization of the manual activity of metal cutting and size reduction, and improving safety and productivity.

Size Reduction describes approaches to improve the safety and speed of the metal cutting to package process equipment that could not be decontaminated.

Building Decontamination and Building Demolition describe methods that improved the efficiency of the activities to remove facility infrastructure, decontaminate building surfaces, and finally demolish the buildings.

Placing the decisions on technology deployment in the hands of the management directly responsible for execution of the activity ensures that the effort remains focused and accountable, and is more likely to be deployed.

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Environmental Restoration describes techniques developed to improve the control of a soil remediation activity for plutonium contaminated soils.

Technology and improvements in work methods in three additional topic areas also substantially improved Closure Project productivity.

Security Reconfiguration describes approaches that were used to make the security requirements for the decommissioning of plutonium facilities flexible and responsive.

Plutonium Packaging describes methods used to process and remove the remaining Site nuclear material, a critical path activity for closure.

Safety System Support identifies approaches that supported the decommission effort to remove restrictions and address the worker safety risk inherent in major construction activities in a contaminated site.

The descriptions of the individual technologies begin by discussing why a technology was needed. The technology process is then described in enough detail that managers can assess whether it might be relevant for their applications. The description concludes by identifying related processes that either support or are supported by the technology.

One element of the Rocky Flats Closure Project planning strategy was the expectation that contractors would find and utilize work process efficiencies during the course of closure.

One element of the Rocky Flats Closure Project planning strategy was the expectation that contractors would find and utilize work process efficiencies during the course of closure. The closure contract committed the contractor to an aggressive target cost and fee, with substantial loss of fee if the target was not achieved and substantial rewards for cost reduction and schedule acceleration. Extrapolating the cost of the Closure Project scope from the cost of previously decommissioned buildings using then-current Site decommissioning methods resulted in an overall closure cost significantly exceeding the contract target. Although some efficiency improvement was expected as a result of management process changes, a significant improvement in the productivity of work processes was needed to meet target costs. Identification and successful deployment of new technologies was a requirement for Closure Project success.

Prior to addressing the nine technology development topic areas, the section discusses the conditions and approach that framed the technology development decisions at Rocky Flats. Since other EM projects will have different initial conditions (such as site history, contaminants of concern, project scope, waste disposition alternatives, and regulatory considerations), the reader is likely to find some technologies more useful than others. Thus, the subsection following this Introduction describes the

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Rocky Flats conditions and strategic closure decisions that impacted technology improvement decisions.

The Closure Project approach to technology deployment is discussed in General Principles of Technology Deployment. The following subsection discusses the nine technology development topic areas. Finally, the section concludes with Key Learning Points that summarize the technology deployment success features from the Rocky Flats Closure Project.

CONDITIONS AND TECHNOLOGY DEPLOYMENT INFLUENCES

Several Site characteristics and decisions impacted which technologies could be effectively employed. Differences between these characteristics and those of future closure projects need to be assessed to determine which technologies might be most beneficial.

Decommissioning is waste processing – it depends on the disposal options and needs to be optimized beginning to end.

The Site production activities were narrowly focused on the fabrication of plutonium, uranium, beryllium, and stainless steel weapons components. This resulted in substantial quantities of Special Nuclear Material (SNM), mostly plutonium and uranium) in purified or concentrated form, sometimes packaged as waste, but often as contamination or "holdup" dispersed throughout the process systems (gloveboxes and tanks). There were over 1000 gloveboxes and numerous tanks within six major mostly-concrete plutonium-process buildings, and a substantial amount of large depleted uranium machining and forming equipment in five other major buildings. The remaining few hundred facilities provided administrative and support functions, and contained little or no contamination. Although there were some organic plumes, they were largely contained within the 380 acre "industrial area," and did not approach the Site boundary. Radiological releases requiring remediation were relatively modest and localized (compared to other major DOE sites), covering approximately ten percent of the industrial area. There were isolated instances of buried radioactive waste on Site, but no major burial grounds or contaminated disposal facilities; historically waste had been shipped elsewhere for final disposal.

Since Rocky Flats contained no high-gamma radiological materials or contamination, much of the material that would become radioactive waste during decommissioning consisted of pieces of equipment that had plutonium or uranium contamination on their surfaces. There was no decommissioning work that could not be done on a "contact" basis (i.e. there is no requirement for remote high-radiation activities such as would be the case for reactor or fission product processing facilities).

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A key element of project scope was that the closure involved the entire Site – there would be no ongoing operations. The path to closure involved removing the SNM and packaged transuranic wastes, deactivation to remove process system SNM "hold-up", substantial facility decommissioning, and a modest amount of environmental restoration compared to the other large DOE sites. The disposition location for residues (those plutonium-laden waste-like materials directly derived from plutonium recovery activities) was determined to be the Waste Isolation Pilot Plant (WIPP). Also, a storage facility was built to manage SNM at the Savannah River Site (SRS). The processing necessary to prepare SNM for shipment to SRS and the residues for shipment to WIPP did not require a major new facility – it could all be done by modifying or installing new equipment into existing processing facilities. The principal decommissioning effort was in the plutonium facilities, which required simultaneous compliance with federal and state hazardous material regulations, safeguards, physical and personnel security, nuclear safety, criticality safety, and radiological safety. The layered and sometimes conflicting requirements complicated efforts to change methods of executing work in these facilities.

Size reduction or repackaging to improve waste packing density was rarely cost effective; these activities were minimized whenever possible.

Rocky Flats obtained a DOE policy decision in 1997 that it would not bury "waste" on site. This meant that all waste had to be suitably packaged for over-the-road DOT-compliant transportation (as opposed to other DOE facilities that may have onsite RCRA or CERCLA cells that can be accessed independent of public roads, and/or make use of re-usable waste containers). It follows that waste disposal had significant costs: disposal fees, container costs, transportation costs, along with the cost and schedule risk from inability to dispose of materials. These costs initially provided an incentive to reduce waste quantities where practical, such as minimizing the generation of low-level waste from facility structures.

The cost of manual work in highly contaminated areas was too high, and there were additional disadvantages for worker safety.

The Site decided to use the surface contamination levels in Nuclear Regulatory Commission Guide 1.86 as the standard for unconditional release of facilities and equipment. Initial plans were to decontaminate facility surfaces to that level, demolish the facility, and either use the demolition debris as fill or dispose of it offsite as sanitary waste. Most of the plutonium facilities were concrete, which could be cost-effectively decontaminated and used for fill on site or transported for disposal at local landfills. In practice, sections of facilities such as floor slabs, and in two cases most of the buildings, were demolished and disposed of as waste at the Envirocare of Utah (Envirocare, now known as Energy Solutions) disposal facility. Risk analysis techniques (as opposed to unconditional release under Reg Guide 1.86) were used to justify leaving contaminated structural materials undisturbed or as fill on the Site after closure in

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specific situations and to support certain "no further action" determinations for environmental restoration areas. The regulators approved their use on a case-by-case basis.

In the final years of the closure project (FY04-05) the Site received no new technology development (TD) funds. By that point there were very few activities that could have benefited from extensive R&D because the TD effort had defined solutions for the Site's technical challenges and the Site was then ahead of schedule to complete the cleanup. DOE HQ decided to focus limited TD dollars on risk reduction at other sites that could benefit the EM cleanup efforts throughout the complex. It is also unclear whether additional TD efforts could have been implemented effectively in the time remaining. However, the Site continued to implement the TD improvements identified in the early years of the project, and worker suggestions and innovations were implemented routinely.

GENERAL PRINCIPLES FOR TECHNOLOGY DEPLOYMENT

The key measures of success for a new technology were the quantifiable improvements it made in worker safety, in reducing activity duration and cost, and in streamlining waste disposition. Choosing which technologies would provide the most improvement at the beginning of the Closure Project was a speculative process. The overall TD approach that achieved the greatest success was to identify technologies that represented incremental improvement within an ongoing process – evolution versus revolution.

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Managers and work crews directly responsible for executing the work were able to identify tangible problems and success parameters, often achieving results with off-the-shelf equipment that had not been previously used for that purpose. Direct connection with the work crews was also important, as technologies that had worker acceptance were more easily implemented. Selected deployment of contractors with narrow technical niches for specific tasks, such as decontamination or characterization of specific types of equipment or structures, also assisted in implementing technologies. These "bottoms-up" methods for identifying and implementing technologies were most effective for longer-term activities, and where conventional methods could be employed immediately, even if inefficiently, and then improved. "Pilot projects," such as the Building 123 and Building 779 projects, started early in the Closure Project allowed evolution in technologies (as well as evolution of management and regulatory techniques) to begin earlier as well.

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For shorter-term or expedited activities that could not be executed with existing technology, a "top-down" approach was used. Identifying and deploying technologies from a top-down perspective depended on the planning and baselining process and on identifying and assigning project and worker safety risk to individual execution activities. Early in the planning process the details of how technically complex activities would be executed was not known. Assigning a risk and contingency cost to activities where methods to execute the work were unknown or poorly defined allowed prioritization of technology development to reduce those risks. Also, knowledge of the estimated activity cost prevented investing in developing technology options that could not substantially improve overall Closure Project costs. Cases occurred where several parallel technology development efforts were initiated in areas of substantial project risk to ensure that at least one suitable method could be deployed – the most notable being glovebox size reduction where a centralized automated facility, local "Birdcage" facilities, and glovebox decontamination were all initiated simultaneously.

For decontamination or size reduction of highly contaminated equipment with diverse plutonium systems, hands-on manual work was more effective than remote or automated action.

Three general principles were found effective in directing the work and hence the technology deployment effort. First, for decontamination or size reduction of highly contaminated equipment with diverse configurations, hands-on manual work was more effective than remote or automated action. Automation proved too inflexible to adapt to the very unique configurations, even less efficient than the expensive and safety-challenging process of workers in extensive personnel protective equipment (PPE) and contamination control enclosures. Second, work options such as glovebox size reduction that required the handling of uncontrolled highly contaminated materials (i.e., not containerized waste) were minimized whenever possible. For example, additional size reduction or waste repackaging to improve waste packing density was rarely cost effective – the cost of manual work in highly contaminated areas was too high, and there were additional disadvantages for worker safety. Finally, activities were outsourced off-Site if at all practical – even if nominally more expensive (within limits). Offsite contracted work avoided some of the inherent DOE Site inefficiencies, interference with other activity schedules and resources, and the diversion of management attention. Through understanding of these issues, technology deployment evolved to focus on minimizing or enhancing manual activities for plutonium decommissioning activities, investing effort in activities that had to be done on Site, and avoiding overly complicated or automated solutions.

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One last principle of the TD program at Rocky Flats was an expansion beyond physical or engineered solutions. TD was broadened to include processes, management, and system innovations that may or may not have an equipment component. Innovation in any form was used to increase

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safety, efficiency, and/or effectiveness. This broader perspective on TD will be apparent in several of the examples described below.

TECHNOLOGIES USED TO ACHIEVE SITE CLOSURE AND AVAILABLE FOR DEPLOYMENT AT DOE CLOSURE SITES

The technologies discussed below are given generally by topic area – Waste Packaging, Equipment Size Reduction, etc. Each technology discussion begins by explaining the drivers for developing that technology, to help the reader decide whether the technology might have any application for their site or project. The discussion continues with a brief description of how the technology is deployed or what was done. The description is not intended to provide sufficient detail to allow the reader to recreate the technology; it is intended to inform a reader that the technology exists and has been successfully demonstrated at Rocky Flats. The technology discussion ends by identifying other technologies that were associated, typically synergistically, with the described technology to ensure that the impacts of that technology are viewed within the overall Closure Project context.

The first six sections below discuss decommissioning and cleanup technologies that are generally applicable to a variety of DOE facilities. The final three sections address more specialized technologies key to the success of the Rocky Flats Closure Project.

A. Waste Packaging Innovation

Waste packaging and its association with the waste management efforts to reduce waste disposal costs were critical to the successful acceleration of Rocky Flats closure. While some of the innovations reduced the cost of handling packaged waste, the greater impact of the technologies was the ability to reduce the cost of the actual decommissioning effort itself. The waste packaging activities in this section dealt mostly with decommissioning-generated waste. The waste activities dealing with more concentrated "residue" materials are discussed in the Plutonium Packaging topic area.

<u>Characterization of Materials using Surface Contaminated Object (SCO) Procedures</u>

The driver for developing the SCO procedure was the need to characterize larger pieces of equipment to be shipped as waste with the minimum of size reduction. The characterization method had to assure that the overall package contents had transuranic radionuclide concentrations less than

100 nanocuries/gm and could be definitively determined to be low-level waste (LLW) and not transuranic (TRU) waste. This was a particular problem for plutonium-contaminated equipment due to the low gamma emissions.[113]

The process employed was the statistical surveying and sampling of equipment surfaces to calculate the total activity (nanocuries) of the individual items placed in the package, which were summed to yield an average contaminate concentration and total package activity. It relied principally on direct alpha readings of interior as well as exterior equipment surfaces, readings often in excess of one million counts per minute. The process depended on the majority of the hard-to-size-reduce materials being contaminated exclusively on the surfaces, and not within the material matrix. Previous characterization procedures required all materials in process areas to be size reduced sufficiently to meet the geometry requirements of non-destructive assay (NDA) equipment (i.e. 4 ft. by 4 ft. by 8 ft. maximum). The SCO process allowed equipment to be packaged in cargo containers or larger sizes, limited only by over-the-road transportation constraints, and avoided substantial manual size reduction.

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An initial effort early in the Closure Project validated non-process materials in operating areas as being much less than TRU concentration. Characterization accuracy improved until process equipment could be surveyed, and selected parts of equipment could be decontaminated or removed to leave the majority of the piece less than 90 nanocuries/gm. The SCO characterization results were validated by NDA techniques. The SCO characterization process benefited from improved characterization and survey instrumentation, better waste profiling procedures, the use of cargo containers for disposal of larger pieces of equipment, and glovebox and tank decontamination improvements.[114]

The improvement in speed, efficiency, and worker safety that resulted from minimizing process equipment size reduction was one of the biggest technical factors in the Closure Project success. A second major consequence was a dramatic reduction in the volume of TRU waste. The cost of TRU waste transportation and disposal was a general EM departmental cost not specifically included under the Closure Project costs. Even without the EM savings in transportation and disposal costs, the reduction in TRU waste still resulted in a substantial waste savings for the overall Closure Project since the costs to characterize and manage the waste containers were typically much higher by volume for TRU than for low-level waste.

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Use of Cargo Containers as LLW Packaging Containers

The driver for the use of cargo containers as waste packages was the need to minimize size reduction of equipment using an inexpensive, easily handled over-the-road transportable container.[115] Previous to cargo container use, relatively small portions of LLW materials had been placed in wooden crates with a volume of about one hundred cubic feet. Minimum Department of Transportation (DOT) regulations for radioactive waste shipping of LLW required strong, tight containers, and the Nevada Test Site waste disposal facility (NTS) could readily handle cargo containers at a reasonable disposal cost. Cargo containers, ranging in size from one thousand to two thousand cubic feet, were particularly useful for more highly contaminated LLW and equipment that might puncture or otherwise compromise less robust containers. They were easily handled on Site and large enough to take many types of equipment with minimal size reduction. Effective use of cargo containers benefited from the implementation of the SCO characterization of contaminated equipment and the use of non-expansive foam for filling the package voids, and improved container loading techniques.

Cargo containers provided an inexpensive, easily handled, over-the-road, transportable container that minimized the need for size reduction.

Structural Foam/Encapsulant

The driver for implementing the use of container foaming was to avoid the shifting of cargo container contents in transit and the attendant potential to breach container containment.[116] Additional benefits were the abilities to meet disposal facility subsidence requirements and to provide an additional "layer" of contamination control. Original procedures for cargo container packaging required custom carpentry to provide wood blocking and bracing to maintain container integrity while in transit to the disposal site. The new process consisted of filling the cargo container with non-expansive foam after the container had been filled with waste, certified, and closed. After a tank or glovebox had been determined by SCO characterization to be non-transuranic, it may have been filled with foam. Foam was inserted using a small drilled hole and standard industrial foaming system. The deployment of waste package foaming improved the packaging process for cargo container shipment. Foam was later used for other uses, although when used in very large void areas heat generation during curing and resultant combustion potential became a limiting factor.

After the cargo container had been filled with waste, certified, and closed, it was filled with non-expansive foam to avoid the shifting of contents in transit and the attendant potential to breach container containment.

Dealing with Glovebox Lead Shielding

Gloveboxes containing equipment that processed large quantities of plutonium usually had lead shielding to reduce the radiation exposure of the process operators, with the lead being attached in a variety of ways. During decommissioning the lead was normally removed from gloveboxes

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being decontaminated for disposal as LLW (i.e., activities less than 100 nanocuries/gram), because allowing the lead, a hazardous constituent, to remain would cause the glovebox sections to be low-level mixed waste (LLMW), and LLMW with activities greater than 10 nanocuries/gram did not have a convenient disposal path.

While this approach was reasonable for most gloveboxes, many of the gloveboxes in Building 371 were fabricated with the lead sandwiched in stainless steel compartments covering the glovebox surface. To remove the lead, the D&D worker would first have to remove the outer layer of stainless steel and then chisel off the lead, an extremely laborious process. The Site identified an approach to decontaminate the glovebox to less than 10 nanocuries/gram and then worked with Envirocare to fill the glovebox with foam to stabilize the internal contamination and meet Envirocare's waste acceptance criteria.[117]

Improved Cargo Container Loading

The driver for improving the cargo container loading was to avoid removing individual pieces of waste from the contamination controlled area to cargo containers located in clean areas, with the resulting inefficiency. Two general approaches were used. Special doors and airlocks were developed to allow the cargo container to abut the building walls, allowing the cargo container interior to become part of the contamination controlled area.[118] The airlock doors allowed the pressure integrity of the facility to be maintained while the cargo containers were changed. Doors were placed at the levels needed, which required use of hydraulic platforms for second story doors and excavation for basement doors. In cases where size reduction was less of a concern, cheap cardboard boxes that could be nested in the cargo containers were used to collect materials throughout the building and then moved to the waste loading area and placed in the cargo containers.[115,119] These boxes allowed more efficient packing of the cargo container, more efficiently using the space at the container top.

Special doors and airlocks were developed to allow the cargo container to abut the building walls, allowing the cargo container interior to become part of the contamination controlled area

Use of Railcars to Transport Low Level Waste

For most of the project, shipping of LLW was conducted by truck transport. This was acceptable in the early phases of the decommissioning. Waste generation rates were lower and the wastes more contaminated as the D&D workers were mostly hand-removing the process systems and associated equipment. As the project progressed to higher waste generation rates, mainly due to the demolition of contaminated facilities and ER activities, it became clear that truck shipments involving reusable containers (e.g., intermodals) would not be

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efficient. The lower waste contamination levels allowed the use of soft-sided containment and bulk disposal using rail gondola cars. Demolition of the larger facilities provided an opportunity for point-of-generation shipping that justified the expense of expanding onsite rail lines. Rail spurs were constructed beginning in 2004, extending existing lines to areas adjacent to Building 776 and Building 371. Other precursors to rail shipment were the development of authorization bases that allowed open air work with bulk contaminated materials and regulatory approval (achieved through the implementation of selected RFCA Standard Operating Protocol). Each railcar held as much as 100 tons of waste, the equivalent to seven trucks. Larger containers allowed workers to spend less time size-reducing large pieces of equipment, building structural elements, and rubble with significantly less worker exposure to safety hazards. It also removed approximately 5,000 trucks from the highway, reducing the chance of public accidents.[100, 120]

Development of the "InstaCote" Process for Packaging Large Pieces of Equipment

Thousands of man-hours of difficult and dangerous size reduction in anti-contamination clothing were avoided by use of InstaCote.

The driver for developing the "InstaCote" packaging process was to avoid size reduction of large pieces of equipment – pieces too large to fit in a cargo container (e.g., in lieu of diamond wire cutting, etc.).[121] Some pieces of uranium metal forming equipment had been purchased and received as a single massive unit, and would have been difficult to size reduce to fit into the 8' X 8' X 30' maximum size of cargo containers. Instead of creating custom strong, tight boxes around the equipment, the "InstaCote" process was developed. The oversized equipment is placed on a strong (typically custom) pallet, shrink wrapped, and sprayed with multiple layers of "InstaCote" polyurea coating (similar to truck bed liner) to form a DOT "strong-tight" container. The ability to characterize the equipment using the SCO process supported the use of "InstaCote" packaging. Easily thousands of man-hours of difficult and dangerous size reduction in anti-contamination clothing were avoided by use of InstaCote.

Preferential Use of Larger TRU Waste Containers (Standard Waste Boxes)

The driver to use standard waste boxes (SWBs) instead of drums was the desire to minimize the size reduction of equipment and to reduce the number of containers of TRU waste to characterize and handle. Disposal of TRU waste in 55-gallon drums had been the packaging method of choice due to the easier physical handling of the smaller containers and the belated development of NDA techniques for SWBs. However, for all but the smallest items of equipment, the use of 55-gallon drums resulted in either considerable unused (void) space or additional size reduction of

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materials at a substantial labor and worker safety cost; the use of SWBs resulted in improved packing density. Also, the costs for managing the wastes correlated strongly to the number of containers handled, i.e. the costs are similar for drums and for SWBs, although the SWB waste volume is nearly ten times greater. Thus, SWBs were used whenever practical, with occasional relatively minor exceptions (e.g. use of drums of Raschig rings and sludge based on NDA considerations).

Worker safety often leads to improved cost and schedule efficiency when it focuses on improving methods for achieving work.

For the Site to use SWBs for the TRU waste generated from the size reduction of process equipment there needed to be an efficient means of reliably determining the fissile material quantity. The Site worked with LANL to implement the upgrade of LANL's original high-energy neutron counter, implementing the "Super-HENC" as a mobile unit. The Super-HENC was then integrated into the Site TRU waste characterization process.[122] The increased use of larger TRU waste packaging also depended on the upgrading of Site TRUPACT II loading capabilities and the consolidation of TRU waste codes to avoid unnecessary segregation.

Tracking Waste to Improve TRU Waste Management

While Rocky Flats had long experience with a database that tracked some waste information on a container-by-container basis, prior to beginning the closure process much of the information required as part of the quality assurance process was contained on "travelers" attached to the containers. Information collected on the database was manually keyed into the database resulting in delays, errors, and incomplete information. As the waste generation increased, particularly the TRU generated from residue processing, a system was implemented using bar codes, scanners, and direct input from certain characterization equipment. The system resulted in improved residue process control, a substantially reduced entry error rate, improved efficiency, reduced worker exposure, and better waste quality assurance program compliance and traceability.[123]

Gas Generation Testing to Improve TRU Waste Characterization

The requirements for shipping and disposing of TRU waste include criteria on the quantity of hydrogen that may be present within the waste and provides a standard formula that may be used to estimate the hydrogen based on the TRU activity and packaging configuration. The requirements also allow for direct testing of the hydrogen levels in the waste drums or other approved containers. As the Site moved to dispose of higher activity residues and wastes, use of the standard formula would have resulted in packaging or repackaging materials into containers with as little as 9 grams of plutonium per drum, well below the 325 grams of plutonium otherwise allowed. The Site developed and qualified a testing system to

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measure the actual levels of hydrogen in the drums that included providing the reproducibility and quality assurance necessary to receive appropriate disposal site and regulatory approval. The mobile system allowed drums to be characterized in their storage location with relatively little additional movement.

Had the Gas Generation Testing system not been implemented the Site would have had to package and load 17,000 additional drums of TRU to dispose of the same quantity of actual waste.

As a result of using this system the Site was able to place more plutonium in each drum. Had this system not been implemented the Site would have had to package and load 17,000 additional drums of TRU to dispose of the same quantity of actual waste. Moreover, the DOE would have had to transport, and the WIPP site would have had to dispose, this additional volume. The Site additionally would have had to repackage numerous drums that were otherwise suitable for disposal, [124] incurring considerably greater cost, schedule, and personnel exposure.

Use of Reusable or Flexible Container Systems

The driver for selecting differing containers to support the closure activities was to reduce the overall process cost for the decommissioning packaging effort, waste containers, transportation and disposal. It was also used as an external wrapping to ensure container DOT compliance instead of repackaging.[125] For numerous wastes (such as soil, tanks, or other materials), nominally 8-mil plastic covers or sacks were cheap, convenient, DOT-approved, strong-tight containers. Containers were purchased in various sizes and shapes to fit in frames (for soil loading), reusable gondola cars, [100] or end-dump trailers; or custom made to fit specific equipment. Reusable "intermodal" containers transported by truck or rail provided another alternative (although they still required liners for contamination control).

Container decisions depended on transportation distance to the disposal location, disposal site handling and emplacement requirements, differing disposal fees, project conditions and loading facilities, and type and activity of the waste. The bulk of the Rocky Flats radioactive waste was disposed of at WIPP (TRU waste), NTS (LLW) and Envirocare (LLW and Low-level/RCRA mixed waste), with selected smaller waste streams disposed of at other disposal facilities. The other technologies that most impacted the container choices were facility and equipment decontamination methods, and facility demolition approach.

B. Glovebox and Tank Decontamination

Since the most technically challenging portion of the Closure Project was the plutonium process decommissioning, the technologies used to address preparation for its removal are discussed in more detail. The ability to

decontaminate process equipment and avoid the TRU waste generation and size reduction effort resulted in substantial cost savings to the Closure Project.[94]

Cerium Nitrate Decontamination Process

The driver for use of the Cerium Nitrate process was to reduce TRU waste volume, reduce residual contamination levels to make size reduction safer, and reduce the amount of size reduction by disposing of more process equipment as larger pieces of LLW. The process involved the use of a "superoxidant" as a solvent to extract the plutonium oxide from the contaminated surfaces (mostly gloveboxes and tanks) and allow it to be readily wiped or washed off. This decontamination enhancement reduced surface contamination and overall radioactivity, in most cases to below TRU threshold concentrations.[114]

Cerium Nitrate was also effectively used in a remote spray application inside tanks for decontamination, reducing activity levels to low-level waste, and avoiding size reduction and manual work in confined spaces.

One particular success in the use of Cerium Nitrate was with Building 371 gloveboxes that had been fabricated with lead shielding sandwiched within the glovebox walls. If the shielding was not removed (removal was an expensive and time-consuming effort) the size reduced gloveboxes would become low-level/RCRA mixed waste, which could not be disposed of at the NTS facility and were subject to radically reduced radioactivity limits if disposed of at the Envirocare facility. An equally undesirable alternative was the size reduction and TRU disposal of all of the gloveboxes. The Cerium Nitrate process was effective in reducing the contamination concentration to less than 10 nanocuries/gm, an order of magnitude below levels previously consistently achieved. This allowed large pieces of glovebox to meet the Envirocare waste acceptance criteria as low-level/RCRA mixed waste at a considerably reduced overall effort and cost. Cerium Nitrate was also effectively used in a remote spray application inside tanks for decontamination, reducing activity levels to low-level waste, and avoiding size reduction and manual work in confined spaces.

The decontamination method worked in combination with SCO characterization and use of cargo containers to minimize the size reduction of highly contaminated equipment. It was developed and used in parallel with Acid-Base Decontamination Process (some substrates were better addressed with Cerium Nitrate, others with the Acid-Base process). It was used subsequent to the Raschig Ring Vacuum for tanks and with strippable coatings for surface decontamination.

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Acid-Base ("Three-Step") Decontamination Process

The driver for use of the Acid-Base process was the same as for Cerium Nitrate, to reduce TRU waste volume, reduce residual contamination levels to make size reduction safer, and reduce the size reduction required by allowing more process equipment to be disposed of as larger pieces of LLW. The process involved the use of a proprietary multi-step process to extract the plutonium contamination from the contaminated surfaces (mostly in gloveboxes) to reduce overall radioactivity, in many cases to below TRU concentrations.[126] The decontamination method worked in combination with SCO characterization and use of cargo containers to minimize the size reduction of contaminated equipment. It was developed and used in parallel with Cerium Nitrate Decontamination Process (some substrates were better addressed with Cerium Nitrate, others with the Acid-Base process).

Use of Vacuum Systems for Removal of Bulk Contaminated Material

Use of the raschig ring vacuum prevented worker contamination while packaging the rings in disposal-compliant containers.

Two systems were deployed at the Site that used suction equipment to remove bulk contaminated equipment, one to remove raschig rings from tanks and one to remove gravel from pits. The driver for the use of the raschig ring vacuum was the need to remove glass "rings" (used to prevent nuclear criticality in tanks), to prevent contamination uptake by workers and puncturing of protective clothing, and to package the rings in disposal-compliant containers. This was a particularly large problem at Rocky Flats, with hundreds of large tanks filled with raschig rings, i.e. 1-1/2 inch diameter by 1-1/2 inch long hollow cylinders of borated glass. The process[127] used a specialty vacuum cleaner with sufficient power, exhaust filtration, and criticality controls as an alternative to hand-removal. This technology interacted with Cerium Nitrate to allow its use for decontaminating tank interiors, thereby avoiding or reducing the need for size reduction. Raschig rings in drums, the waste packages resulting from the process, could be more accurately assayed to determine whether the waste was TRU or LLW.

In Building 776 pits up to 18 feet in depth containing potentially contaminated gravel inside the building represented a significant and unique technological problem. The Site obtained a vacuum system similar to that used in mining operations and modified it to act as its own shipping container. It installed sufficient HEPA filtration to ensure that radioactivity was not spread during the vacuum operation.[128]

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C. Size Reduction

The size reduction of plutonium processing equipment to allow it to be packaged in TRU waste containers presented particular worker safety and cost efficiency challenges.

Plasma Arc Cutting

The driver for plasma arc cutting of contaminated metal was the need to increase the speed of size reduction in ways that reduced worker stress, fatigue, and potential for injuries (versus hand-held reciprocating saws), but retaining the flexibility to cut varied shapes. Plasma arc cutting[129] used hand-held plasma-arc cutting torches to cut metal at several times the cutting speed of standard hand-held saws. Additional fire risk and contaminant dispersal limited the use of this technology to more controlled environments. This technology depended on the "Birdcage" containment systems and glovebox and tank decontamination techniques to reduce and control contaminant spread. The combination of equipment decontamination, SCO characterization, and LLW disposal was a competing technology. Over time this combination of technologies reduced the percentage of contaminated equipment that required size reduction, and reduced the impact of the plasma arc process. However, there was always a substantial quantity of the process equipment that was best handled through size reduction.

Plasma arc cutting of contaminated metal increased the speed of size reduction in ways that reduced worker stress, fatigue, and potential for injuries, yet retained cutting flexibility.

"Birdcage" Containment

The Birdcage Containment system[129] came out of the need to control radioactive airborne contamination during equipment size reduction. Early in the Site's decommissioning of plutonium-contaminated gloveboxes, high airborne contamination levels ("derived air concentration", or DAC) exceeded operating parameters for workers in supplied air suits. To provide additional physical controls to reduce the DAC, Rocky Flats developed "cabinet" enclosures to provide an additional layer of containment within larger soft-sided containment structures. These cabinets were large enough to surround the glovebox, and provided airflow control to remove contamination from the worker environment. The cabinets had portable cutting tools suspended from retractable load-bearing cables to reduce worker fatigue. Workers would then reach inside the cabinet to perform size reduction work, hence the name "birdcage." This better control of airflow reduced the airborne contaminants to levels where workers could work in lower levels of PPE and reduce potential for skin contamination (due to lower levels of surface contamination on PPE and work surfaces). However, working partially inside the cabinets degraded ergonomic factors and size reduction

Birdcages were developed to provide additional physical controls to reduce high airborne contamination levels which exceeded operating parameters for workers in supplied air suits.

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efficiency. This was partially compensated by lighter tooling, aids for gripping and lifting, and other tooling improvements. The Birdcage containment interacted with various tooling improvements and the plasma arc cutting to provide an improved method to deal with large, extremely contaminated equipment not suitable for decontamination. It competed with the combination of equipment decontamination, SCO characterization, and LLW disposal as a method to dispose of highly contaminated equipment, and to some degree with fogging as a means of airborne contamination control. Better training and experience allowed workers to reduce levels of physical controls over time while maintaining DAC and surface contamination at acceptable levels.

Improved Size Reduction Procedures, Training, and Experience

The driver for improved work processes was to provide continued improvement in safety, work efficiency, and contamination control. The approach depended on getting work started, even with heightened controls and less-than-optimal efficiency, and then provided continued worker and first-line supervisor feedback for size reduction methods, contamination control, and procedure and paperwork requirements. This typically involved engineering and operations staff under a common project manager, and supported continued improvement in efficiency and introduction of new techniques. The approach addressed workflow bottlenecks such as reducing unnecessary movement between controlled and uncontrolled areas, locating waste containers convenient to work locations, and other means of reducing unproductive time. It interacted to implement and enhance the impact of new technologies and benefited from organizational cooperation, and Safety System Support. Although these actions were not TD in the typical sense, they represented continuous opportunity for innovation, and particularly innovation linked directly to the needs of the workforce. In this way they continually supplemented and reinforced the other TD efforts.

D. Building Decontamination

Decommissioning is a crude business that requires flexibility and resists elegant solutions

Building decontamination was defined as both the removal of contamination from facility surfaces (as opposed to highly-contaminated process equipment), and also the removal of equipment associated with the facility such as heating systems and ventilation ducting. Decontamination of facility equipment located in operating areas was not cost effective. The cost of equipment characterization in plutonium facilities for unrestricted release was typically greater than the cost of disposal as LLW. For uranium facilities, the different release levels allowed cheaper characterization of unpainted surfaces; as a result, a large

portion of the support equipment was released and disposed of as sanitary waste.

Fogging

The driver for fogging was the need to reduce the airborne contamination (i.e., DAC) present in rooms to acceptable levels for workers in more work-efficient forms of PPE. Very high DAC levels were often present in canyon or vault areas, and were exacerbated by work activities that disturbed and suspended contaminated dust. The Fogging process[130] involved the use of a device to diffuse an aqueous aerosol (i.e., "fog") containing glycerol through an opening into the contaminated room or space, effectively "scrubbing" the air of particulate. Upon drying, the highly mobile contaminated dust was deposited on surfaces, reducing the airborne contamination levels by orders of magnitude. The deposited glycerol was much less susceptible to resuspension, although it was soluble and could be subsequently decontaminated from facility surfaces. The process interacted with technologies using strippable coatings; these were polymeric coatings sprayed on surfaces that would bind the glycerol-immobilized contamination, either for further decontamination (by stripping the coating off the surface after it was dry) or for reduction of surface contamination levels to improve area working conditions. Dyes that fluoresced in ultraviolet light could also be added to the fogging liquid to allow easy identification of contamination on clothing during removal of personal protective equipment.

Ultra-high Pressure Abrasive Water Jet Cutting

The driver for using water jet cutting was the need to cut large, moderately contaminated equipment, while suppressing airborne contamination and reducing the need for contamination control enclosures. The process[131] used water jets containing abrasives at pressures greater than 10,000 psi to cut contaminated metal equipment such as tanks and vessels. Equipment had to be under conditions where liquids were contained, and contamination was at levels below which criticality was a concern, and the water lances were a safety concern – they were difficult to control, and could easily cut flesh, electrical cables, and conduit. Using technologies that allowed the recycling of water was advantageous to minimize liquid waste generation.

Water lances were a safety concern – they were difficult to control, and could easily cut flesh, electrical cables, and conduit.

Chipless Duct Cutter

The driver for developing the chipless duct cutter[132] was the large quantity of highly contaminated cylindrical exhaust duct that maintained the negative pressure differential for process equipment, and connected the

gloveboxes to the filter plenums. The duct was difficult to remove due to its often-inaccessible location, the difficulty in fixing contamination within the duct, and difficulty in erecting contamination barriers (e.g., soft-sided containment). Saw cutting resulted in a substantial spread of contamination and increases in the level of airborne contamination, as well as higher injury rates from the reciprocating saws.

The process was to use a rotating cutter (similar in principle to a pipe or tube cutter), where knives were rotated around the cylindrical duct until the duct was sectioned off. The cutter could be operated in a small semi-enclosed contamination control enclosure to minimize contamination spread, due to its proximity to the duct and the relatively low ejection of contamination during cutting (as opposed to a saw blade that moves in and out of the contaminated duct interior). Limited set up area allowed work to occur in confined or elevated areas such as duct or pipe chases. Round duct was removed in sections convenient for packaging, with duct ends sleeved and tied off – the duct interior was not exposed to the work environment during handling. The technology interacted with rigging and access enhancements such as lift tables, improvements in contamination control enclosures, and improvements in training and procedures.

Explosive Cutting

The driver for explosive cutting[133] was worker safety, in particular to avoid elevated work with heavy materials on scaffolds. The process involved using small charges to cut bolts, hangers, and other metal and masonry materials, principally to take elevated materials and drop them to floor level for further processing. As an example, large uranium facility duct located at high-bay ceiling level could be cut in large lengths by workers on man-lifts while it was still suspended, and then the hangers cut explosively to lower it to the floor level for further size reduction. Explosive cutting was done during off hours with workers removed from the building. The technology was supported by powered and hydraulic equipment.

...small hydraulic equipment could either be used to grasp, shear, and pneumatically hammer materials such as duct, conduit, walls, and piping to avoid manual handling.

Building Interior Powered Hydraulic Equipment

The driver for use of powered and hydraulic equipment inside buildings[134] was improved worker safety and efficiency on materials where contamination spread could be controlled. The process utilized small hydraulic equipment that could be used to grasp, shear, and pneumatically hammer materials such as duct, conduit, walls, and piping to avoid manual handling. “Bobcat” vehicles were also used to support loading of masonry and other materials into waste containers. Extra industrial safety precautions were required to provide adequate ventilation for workers in

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rooms with the propane or natural gas-powered vehicles, and training and safety controls for equipment operation.

Treatment Approach for Low Level Mixed Waste Sludge

The largest legacy LLMW stream that was handled during the Closure process was approximately 732,000 gallons of pond sludge. The pond sludge resulted from the Site's draining of its solar evaporation ponds in the 1990s, which had resulted from a failed solidification attempt and substantial regulatory conflicts. The sludge was stored in 79 fiberglass 10,000-gallon tanks on a RCRA-permitted pad under large tent structures. The Site conducted extensive treatability studies to assure that the solidified product materials would contain no free liquids and be LDR-compliant. After receiving regulatory approval, the Site processed the sludge – mixing it with polymer and other chemicals – and placed the resulting materials in intermodal container for transportation to the Envirocare facility. The tanks were partially size reduced to allow better access to the residual materials, and then the tank bottom was itself cut up and disposed of as waste. The process had to address different sludge densities and constituents and the difficulty in pumping such inconsistent materials.[135]

Another LLMW sludge stream resulted from the draining of two large steel evaporator feed tanks. The sludge was pumped out using a remote lance system and processed through a centrifuge to increase the solids concentration. The resulting sludge was packaged in drums and SWBs and sent to Envirocare for final treatment and disposal.[136]

Hydrolazing

The driver for the use of hydrolazing[137] was that, for plutonium facilities, most of the contamination on concrete was near the surface, in many cases encased in layers of paint. There was a need for a means of rapidly removing paint and upper surfaces of concrete without causing contamination spread or airborne contamination. The paint removal was also necessary to allow surveying of the underlying structural surfaces to determine residual contamination levels for facility release, since the paint also masked surface alpha readings.

The hydrolazing process used an ultra high-pressure water spray that readily removed the paint and surface layer of concrete without creating substantial airborne contamination.

The hydrolazing process used an ultra high-pressure water spray that readily removed the paint and surface layer of concrete without deep penetration and without creating substantial airborne contamination. The decontamination technology was less sensitive to cracks and small variations in surface smoothness than some mechanical decontamination techniques. Initially spray nozzles were hand-held which represented a

safety hazard. Subsequently, the spray nozzles were mounted within a contained, movable, vacuum-supplied enclosure similar in size to a lawnmower housing. The water and solids were vacuumed into a cyclone separator with a filter that separated the solids as a waste sludge and allowed the recycling of the water. The movable enclosure was deployed from a hydraulic boom to decontaminate floors, walls, ceilings, and (with a special enclosure) columns. Results were generally good, although in some cases the process appeared to drive contamination further into the concrete. The technology was dependant upon the liquid waste treatment technology to allow recycling of water and used in conjunction with concrete cutting, scabbling or impact hammering for removal of the "hot" spots identified after the surface paint has been removed. It competed with cheaper dry surface techniques like concrete shaving, particularly in uranium buildings.

Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Survey Techniques

The driver for using MARSSIM survey techniques was the need to use an approach to release facilities that was efficient and had credibility with the public and regulators; 100% surveying of all potentially contaminated facilities would have been prohibitively expensive. Various governmental agencies had certified the MARSSIM methods to characterize facilities and environmental sites. The methods used statistical survey techniques and risk assessments to determine residual contamination levels, depending on the method of disposal and/or the future use of the site. Rocky Flats chose to use the MARSSIM statistical survey techniques supplemented by 100% surveys in selected areas to support waste determination and facility/material unconditional release. The risk assessment component was included for environmental restoration activities. Interior walls could be segregated and removed piecemeal as sanitary or recycled material after release. The ability to effectively employ the MARSSIM approach for unconditional release of facilities was dependent on effective radiation survey instrumentation and database management, [138] and on early agreement with regulatory organizations regarding the exact release requirements and techniques.

MARSSIM survey techniques provided an approach to release facilities that was efficient and had credibility with the public and regulators and avoided 100% surveying of all potentially contaminated facilities.

Ventilation Stack Characterization

The ventilation exhaust stacks for contaminated facilities represented unique demolition problems. Uncontaminated stacks are normally demolished by explosively removing a portion of the stack base and causing the stack to topple into a designated impact area. Water sprays are used to reduce the dust that otherwise becomes airborne on impact. Manual dismantlement, an approach that might be used to minimize dust

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emissions from a lower-profile contaminated structure, would entail substantial safety risks (and/or costs to avoid that risk) due to the stack height and configuration. Similarly, manual surveying that might be routine for building interior surfaces becomes difficult inside of a stack.

The Site developed an automated system that could be placed on the top of the 170-foot Building 771 stack by a crane that would progressively lower instrumentation suitable for detecting contamination on the interior stack surfaces. The system provided scans of 676 locations, four per axial foot that allowed the majority of the stack to be unconditionally released. Along with some additional surveys at the stack base, the use of this system allowed the whole stack to be demolished using conventional explosive demolition techniques.[139]

Use of Radio Frequency Alarms as Buildings Go "Cold & Dark"

During the decommissioning process the electrical power and utility services were removed from a building to reduce the possibility of worker injury from electrical events. There were cases where sufficient combustibles remained in the building to require fire detection and suppression. In order to avoid rewiring the fire alarm system the Site developed a system that interfaced with existing fire detection systems to provide the necessary fire detection coverage. The system was solar powered and used wireless technology to interface with the Site fire alarm system.[140]

E. Building Demolition

Demolition was defined within the Closure Project as the demolition of the facility after all of the equipment and contamination had been removed, with the facility being as close to an uncontaminated facility as practical.

Explosive Demolition

Explosive demolition was far more effective for smaller scope applications, such as towers and stacks, and the harmonic delamination of concrete walls.

The driver for explosive demolition[141] was worker safety; i.e., removing workers from the vicinity of unstable structures, and to improve demolition efficiency for concrete buildings. The major difficulty was coordination with public and regulatory organizations to ensure their support, and to assure the public of the Site's ability to control any release of radioactivity through decontamination, modeling, water spray, monitoring, and test projects. The explosive demolition process used commercial explosive demolition contractors to explosively cut the building structural members and allow the structure to collapse upon itself, or implode. The resultant debris was then most often disposed of as

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sanitary waste or as recycled concrete using standard construction equipment; in selected cases the debris was left in place with regulatory approval. Explosives were used to topple air stacks and to crack massive (eight-foot thick) concrete walls through "harmonic delamination[197]" to ease size reducing the concrete by conventional hydraulic hammers. Prior to demolition, building surfaces were first decontaminated to release levels (or acceptable residual contamination levels). During demolition, water sprays were used to reduce fugitive dust emission and local air monitored to confirm the presence or absence of contaminant releases. Although the demolition is rapid, there were substantial preparation times, some of which could not be conducted in parallel with in-building activities. The building structural members needed to be weakened so that the final explosive detonations would confidently collapse the structure. This added additional structural engineering analysis to verify that adequate building structural integrity was maintained for worker safety. The technology depended on decontamination and surveying techniques and on air dispersion and other computer modeling of short and extended-duration demolition activities. Transport of explosives on Site also provided significant security and safety authorization basis challenges. Based on these additional challenges required to implement explosive building demolition, it was only used for one large facility. Explosives were far more effective for smaller scope applications, such as towers and stacks, and the harmonic delamination of concrete walls.

Commercial Demolition

The driver for use of commercial demolition, i.e. use of large hydraulic equipment often mounted on tracked excavators, was to avoid putting workers in harms way and improve efficiency. The process was similar to that used for explosive demolition, in that the building surfaces were decontaminated to release levels (or acceptable residual contamination levels), and then the construction trades used standard large construction excavators with hydraulic shears, hammers, etc. Significant quantities of water were sprayed on the sections being demolished to reduce fugitive dust emission, and air monitoring conducted to demonstrate the absence of contaminant releases.

In some instances steel plates were used to cover and protect clean rubble from re-contamination during demolition.

When the buildings contained contaminated structural members and their removal prior to demolition would constitute a worker hazard, this demolition process was more amenable to engineering controls and selective demolition of sections of buildings. Prior to demolition, the radioactivity on the contaminated surfaces was fixed; in other instances steel plates were used to cover and protect clean rubble from re-contamination. The sections were then demolished, and the contaminated materials segregated for disposal as low-level waste. The technology also

interacted with decontamination and survey techniques and methods to provide bulk disposal or recycling of environmental media.

F. Environmental Restoration

The following approaches and techniques were particularly useful in Rocky Flats Environmental Restoration (ER) activities. Some are discussed further in the Environmental Restoration section.

Temporary Structures for Remediation of High-Contamination Areas

The driver for using temporary, movable structures[142] during the soil remediation was the need to cost-effectively provide environmental controls during removal of plutonium-contaminated soil and address stakeholder concern about windborne dispersion. The remediated area had become contaminated in the 1950s from plutonium-containing solvents leaking from drums stored outside. The contaminated soil was relatively near the surface of an area subject to high winds. The remediation project purchased movable sprung structures (tents) large enough to enclose operating construction equipment and a staging area for intermodal waste containers, but small enough to be moved progressively across an area of contaminated soil without disassembly. Additionally, the structures provided better control for soil characterization and higher worker comfort and productivity during inclement weather.

Temporary moveable structures addressed concerns about windborne dispersion during soil remediation, provided better control for characterization efforts, and higher worker comfort and productivity during inclement weather.

On-Site Laboratories to Support Environmental Analyses

The driver for limited onsite laboratory capability was the need for rapid turnaround for analyses of selected contaminants in environmental media. The approach was to provide trailer-based laboratory instrumentation to support the rapid turnaround analyses for the selected contaminants of concern necessary to distinguish the soil to be removed from the soil that could be left in place. Only limited analyses were needed, covering only a limited number of constituents, and with resolution only as necessary to identify whether the constituents were above or below the soil action levels. The analysis process included a data management system and computer-based contaminant map that supported field decisions virtually real-time. Offsite laboratories were used for confirmatory analyses and to provide a complete suite of environmental analyses, at a more competitive price than was available from onsite or dedicated facilities. This technology benefited from improvements in characterization instrumentation for environmental media.

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Contaminated Ground Water Treatment

There were three areas at Rocky Flats of contaminated groundwater, two involving primarily volatile organic compounds and one involving uranium and nitrates. After the removal of the concentrated materials that were the sources of the groundwater contamination, impermeable barriers were installed and the groundwater collected and treated. The treatment systems relied on passive treatment approaches that had relatively low operation and maintenance costs, and operations continue under Legacy Management.[143]

Information Management to Support Remedial Action

As the Site proceeded into the last few years of closure it recognized that its investigation and characterization environmental data would substantially increase. Also, the shortened decision-making process needed for accelerated closure would require improved data organization to obtain the necessary information. The Site implemented an environmental data management system that combined geo-spatial data with its characterization, legacy, and laboratory data to provide a single comprehensive database. The system integrated the data quality and verification and validation processes to provide reliability and to automate and facilitate the compliance process. Finally, the system supported the modeling and risk assessment processes necessary to provide the information to justify remediation decisions.[144]

Under Building Contamination Characterization

In the Rocky Flats industrial area with many contaminated buildings located adjacent to each other it was necessary to characterize the soil under the buildings to properly determine and integrate the eventual remedial actions. Normal drill rigs could not be operated in the buildings and, since the buildings were contaminated, direct drilling through the floor slabs potentially would have released contamination to the environment. The Site's approach was to use Horizontal Directional Drilling and Environmental Measurement while Drilling, a process developed at Sandia, to collect the necessary radiological information. The process used a pneumatic drill head and associated radiation detector to drill under the building foundations from the outside the building perimeter and provide preliminary measurements for selected buildings.[145] As a result of these measurements the Site was able to substantially reduce and bound its estimates of the under building radiological contamination. This supported the planning and discussions with the regulators for allowing major sections of the plutonium facility foundation to remain in place after demolition.

As a result of these measurements the Site was able to substantially reduce and bound its estimates of the under building radiological contamination.

G. Security Reconfiguration

The change of the Rocky Flats mission from production to restoration inherently reduced the Site security risks, particularly as Special Nuclear Material (SNM) and classified materials were consolidated and removed from the Site. What remained was a security infrastructure designed for plutonium operations that was unnecessary and costly, both for the labor and facilities to provide the security and for the closure activity effort and delay to comply with the security requirements. The driver for the security analyses, as well as the associated implementing techniques such as changing the physical security configuration or receipt of waivers, was to reduce the inefficiencies and costs imposed on closure activities by the security requirements while maintaining an acceptable security posture. The following approaches were particularly useful in addressing safeguards and security issues during Site closure. Additional information is provided in the Security Reconfiguration section.

All plutonium processing, storage, and infrastructure was consolidated in an existing structure.

Security Posture Time-phased Analysis

The overall approach for matching the changing security needs and systems was to examine the actual security vulnerabilities and controls against the DOE Material Control and Accountability, and Security requirements to determine which controls were really needed and which were unnecessary or redundant. A parallel effort was to review the Closure activities (a baseline was required), identify which security constraints really were causing additional costs, and define options that would reduce those costs (i.e., where the benefit was greater than the cost of implementing the change). For those activities with a potential net benefit, the Site further evaluated the combinations of physical changes, changes in security processes, or submittal for waivers or variances that could most practically be implemented.

The area that would remain protected, the modified PA, was surrounded by a newly-built physical barrier that provided substantial physical protection and intrusion detection capability.

Protected Area Reconfiguration

The original Protected Area (PA), designed to facilitate production by providing security surrounding all plutonium facilities, imposed unnecessary restrictions for entry/access and personnel security on facilities in which decommissioning was occurring and which did not contain large inventories of accountable materials. The process used to implement the reconfiguration was to consolidate all plutonium processing (PuSPS, Residues) in an existing structure (Building 371), including all storage of SNM, the processing equipment, and infrastructure necessary to support those operations. The area that would remain protected, or the modified PA, was separated by a newly-built physical barrier that

provided substantial physical protection and intrusion detection capability but substituted additional labor-intensive security operations to mitigate for reduced levels of physical security equipment compared to the original PA. The combination of physical security and security operations provided equivalent protection but reduced the installation cost and, more importantly, the procurement, construction, and start up time for a system that would only operate for a couple of years.

The limited storage space within the modified PA required the Site to remove as much lower-grade inventory (Attractiveness Levels D&E) from buildings undergoing decommissioning as well as waste material not requiring additional processing, and to consolidate it into stand-alone secured areas. Facilities undergoing decommissioning outside of the modified PA needed to reduce inventory quantities and assess in-process inventory configuration to allow closure of Material Access Areas. The major PA reconfiguration effort depended on additional physical reconfiguration (e.g. new barriers and intrusion detection systems), effective use of Vulnerability Analyses (e.g. Pipe Overpack Container storage in limited area), and support within various levels of the DOE security organizations with waivers and variances to DOE Orders. It was also dependent upon detailed closure planning to identify time-dependent activities and needs.

Vulnerability Analysis

The driver for the innovative use of the vulnerability analyses process was the need to assess the impact of changes on the overall Site vulnerability based on the combination of risk reduction due to closure and physical changes needed to support closure. The Site Safeguards and Security Plan originally established security requirements based on pre-closure characteristics (e.g. material at risk, threats, and barriers) for selected facilities and areas; the plan was updated yearly and supported by a detailed vulnerability analysis. The process used to develop the vulnerability analyses was the standard methods defined in the DOE Orders; the process used to implement the vulnerability analyses was to incorporate it into the annual Site Safeguards and Security Plan update.

These refinements in the vulnerability analyses for selected areas allowed changes in closure activities that resulted in significant cost improvement without loss of adequate security.

The team developing the annual update conducted detailed vulnerability analyses, modeling analyses to determine risks and consequences based on proposed new configurations and proposed changes to the security posture. The analyses were iterative; if a configuration indicated unacceptable vulnerabilities, planned configurations or activities were changed and remodeled to ensure compliance. These refinements in the vulnerability analyses for selected areas allowed changes in closure activities that resulted in significant cost improvement without loss of

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adequate security. The changes were implemented through the revision to the SSSP with normal DOE-HQ reviews.

One particular characteristic of decommissioning was that SNM materials are often inaccessible – spread in very small quantities in duct systems (requiring many hours for trained D&D workers with specialized tools to remove) or packaged in extremely robust containers (requiring hours and special tools to remove). Incorporating the time necessary for a threat to access and remove these materials into the vulnerability analysis models in many cases supported significant improvement in security posture, and allowed other security elements to be relaxed. A second major factor identified in the analyses was that although there was a loss of capability for the physical security systems particularly in the newly built security barrier, the substantial reduction of distances in the modified PA improved security force response times, partially compensating for the loss of capability. This supported the need to evaluate multiple factors in the vulnerability analyses.

The technical output from the vulnerability analyses served as the basis for requests for waivers and variances and the design criteria for changes to physical configurations and relocation of wastes. The vulnerability analyses benefited from improvements in accountability instrumentation and modeling of SNM in inaccessible areas such as glovebox equipment and ducts, which allowed the use of more accurate SNM quantities and reduced the use of conservative assumptions.

The driver ... was the need to take advantage of flexibility in the system originally designed to support a stable production operation and shown to be unnecessary by a vulnerability analysis.

Waivers and Variances

The driver for implementing waivers and variances to DOE Safeguards and Security Orders and requirements was the need to take advantage of flexibility in the system originally designed to support a stable production operation and shown to be unnecessary by a vulnerability analysis. The process was to review areas where significant efficiencies could be obtained by receiving a waiver or variance, and work with DOE-RFFO and DOE-HQ organizations to receive the waiver or variance. Examples were the variance for safeguards termination authorization of Attractiveness Level D and E materials and “Safeguard Termination Limit” materials to support the storage of such materials outside of the PA prior to shipment as waste, and variances to allow non-standard designs for intrusion detection systems and PA barriers. This process depended on the removal of materials from the Site and physical reconfiguration to reduce overall vulnerability and vulnerability analyses to provide the technical basis for the waivers.

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H. Plutonium Packaging

When the decision was made to cease further plutonium weapons production at Rocky Flats and close the Site, the Site contained the largest SNM inventory of plutonium not fabricated into weapons in the country. It also contained virtually all of the country's inventory of plutonium "residues"- materials containing a high concentration of plutonium but which had not been refined prior to the Site's cessation of production operations. These materials had to be removed from the Site before security operations could be terminated and the Site could be closed, and in fact became the critical path effort for all initial closure efforts. The success of these technology development efforts was due to a long-term vision, coordination of efforts, and a focus on a technical solution to a complex problem; the success was reflected in that these techniques are now the baseline method to dispose of some of these materials as TRU waste. The following approaches were particularly useful in addressing plutonium packaging issues during Site closure. Additional information is provided in the Special Nuclear Material Removal Project section.

Rocky Flats housed the largest SNM inventory of plutonium not fabricated into weapons in the country, and virtually all of the country's inventory of plutonium "residues".

Pipe Overpack Container

The driver for development and implementation of the Pipe Overpack Container (POC) package[146] was to resolve a combination of TRU Waste disposal requirements, including the WIPP-WAC[147] TRUPACT II SARP,[148] and WIPP RCRA Permit,[149] to allow the disposal of residue materials. These requirements resulted from the DOE historically not recognizing that an end to plutonium operations would result in greater quantities of more concentrated plutonium-containing materials being disposed of as waste. The assumptions of TRU waste containing modest plutonium concentrations permeated all risk calculations, and resulted in numerous impediments to Site closure such as small quantities of plutonium allowed per drum. Accepting these restrictions would have increased disposal costs several-fold due to unnecessary processing and buying and handling several times the number of containers. Schedules would have been increased adding years to Site closure. TRUPACT II resources and a significant portion of WIPP's total capacity would have been wasted, at a tremendous cost to DOE and the country.

Developing and validating a hydrogen generation rate testing process provided direct package compliance data that, along with use of vented bags, avoided unnecessary repackaging of TRU waste.

A number of DOE organizations spearheaded by Rocky Flats created a standard package for low-mass/high-activity residues that fit inside a drum to take advantage of the WIPP handling infrastructure, but provided substantially more protection for the material during a transportation accident. This POC package included both six-inch and twelve-inch diameter pipes manufactured to provide protection for small packages in the event of fire or pressurization. The necessary safety and risk analyses

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were performed and the SARP changed to accept the revised package, all of which occurred over a period of years. The POC packaging supported the residue processing, and depended on the development and acceptance of residue characterization techniques since normal TRU waste characterization techniques were not accurate at residue plutonium concentrations.

Residue Processing to Meet WIPP-WAC

The driver for improvements in residue processing was the need to achieve compliance with the WIPP Waste Acceptance Criteria in parallel with the approval of the WIPP-WAC procedures. At the initiation of the residue processing effort the requirements for residue disposal at WIPP had not been completely defined. Definition required continued improvement in quality and processes, and close coordination with the WIPP organization to create the acceptance process to allow shipment of materials. The process included the implementation of NDA techniques and quality assurance processes for different container types and acceptance of residue characterization techniques for items shipped in POCs for which standard WIPP assay techniques were inadequate. Characterization process improvements included changing the TRU waste process designations to streamline shipping logistics and using statistics and process knowledge to characterize residue populations instead of 100% sampling. Developing and validating a hydrogen generation rate testing process provided direct package compliance data that, along with use of vented bags, avoided unnecessary repackaging of TRU waste. Residue processing development benefited from the development of the POC and continuous quality improvement, and improvement of NDA techniques to better address residue concentrations and configurations.

Characterization process improvements included changing the TRU waste process designations to streamline shipping logistics and using statistics and process knowledge to characterize residue populations instead of 100% sampling.

Safeguards Termination

During the development of the disposal path for higher-plutonium concentration materials such as plutonium fluoride and some plutonium oxides, it became clear that the materials were unsuitable for acceptance at the SRS SNM storage facility. The driver for developing and receiving acceptance of the blending process was the need to identify a disposal pathway for SNM materials for which there was no other disposal path. Rocky Flats received DOE Complex support to increase the discard limits for the higher-concentration materials, and developed a simple blending process to allow the materials to be mixed with non-radioactive materials into a form that would meet safeguard termination limits. The process was introduced into active gloveboxes inside the modified PA and operated as necessary to meet the WIPP waste acceptance criteria, concurrent with ongoing plutonium stabilization activities and

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decommissioning activities occurring in the same building. This process was a successor to the residue processing necessary to meet WIPP requirements and the implementation of the POC package.

Plutonium Stabilization System

DOE recognized that the elimination of Rocky Flats plutonium operations, and the need to store plutonium materials for prolonged periods of time, would exacerbate the problems with package integrity and pressurization already present in the stored SNM. This recognition resulted in a new DOE Complex-wide processing and packaging standard for SNM storage. A processing system had been developed and partially fabricated by a consortium to meet this standard. The system included substantial automation and complex mechanical devices designed to minimize operator exposure. The Site recognized that the startup, stabilization, and operation of the Plutonium Stabilization and Packaging System (PuSPS) to compliantly package all of the SNM for storage at the SRS SNM storage facility would be on the critical path to Site closure.

With the focus on accelerating closure, the original complex processing system was substantially reengineered and streamlined to substitute manual glovebox actions for automated actions while maintaining the final packaging systems necessary to meet the receiver requirements. It should be noted that even with the reengineering, the PuSPS system was unreliable and difficult to maintain operational. The largest cost and schedule overruns within the closure project were attributed to the PuSPS. The system was also directed at just the current Rocky Flats inventory and modified to be installed in an existing facility in the modified PA. Installation and operation of the system was also expedited. The ability to implement this technology depended upon the support for package certification (both of the PuSPS product containers and the transportation overpacks), disposition support in designating SRS as the SNM storage facility, and development of improved material characterization technologies. The ability to blend and package plutonium materials for disposal at WIPP that were below the plutonium concentrations required for SNM storage avoided the creation of a plutonium purification process that would have required substantially greater effort and schedule.

The largest cost and schedule overruns within the closure project were attributed to the PuSPS.

I. Safety System Support

The following approaches were particularly useful in addressing Safety issues during Site closure. Additional information is provided in the Safety section.

Decommissioning Basis of Interim Operation (DBIO) and Site Safety Analysis Report

Safety and Authorization Basis documentation previously used at the Site had addressed activities related to plutonium fabrication and recovery, not decommissioning; i.e. the operating processes and not a project. Additionally, the safety analyses were based on operational material-at-risk quantities, levels that are normally removed and packaged prior to the initiation of decommissioning. The driver for developing and implementing improved authorization basis documentation was to better address the risk conditions present during facility decommissioning and recognizing the temporary and time dependent nature of facility closure project activities. Instead of revising the facility-specific Safety Analysis Reports that had provided the Authorization Basis for operating facilities, the Site developed Decommissioning Basis of Interim Operations documents. These documents expedited the regulatory process for the authorization of nuclear facilities and incorporated elements supporting the relaxation of facility authorization basis requirements as packaged plutonium and plutonium-processing systems were decommissioned and removed from the facility. This allowed for a reduction in the compliance activities as the risks were reduced, and precluded the need to revise documents as the facility decommissioning progressed. Concurrently, the Site developed a Site Safety Analysis Report to provide an authorization basis for decommissioning activities in external areas and non-plutonium facilities and to analyze generic activities. The process benefited from the definition of the conditions under which the risk of a nuclear criticality within a facility would no longer be credible, with the resulting removal of requirements and controls.

The DBIO process allowed for a reduction in the compliance activities as the risks were reduced, and precluded the need to revise documents as the facility decommissioning progressed.

Training and Procedures

The driver for providing continuous improvement in training and procedures was the need to avoid an increase in accidents as the occupational safety risks increased during decommissioning. The Closure Project successfully implemented the Integrated Safety Management process to facilitate safe work, track accidents and near-accidents, and respond with improved equipment, training, and procedures. In conjunction, the Closure Project continued to streamline work packages to provide the appropriate level of detail to allow work to proceed safely without unnecessary actions or work stoppages. For higher risk activities, particularly in contaminated environments, the Closure Project utilized approaches to ensure better control of the safety environment. This included selected use of better-trained Site personnel (i.e., D&D workers) and subcontracting work with substantial prime contractor management involvement. Additional training was provided as new techniques were

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being implemented and as safety statistics provided indications of accident or near-accident trends. The execution of pilot projects early in the Closure Project provided experience that was used throughout the project.

KEY LEARNING POINTS

1. The technologies that will be applicable to a closure project will vary based on the kind and magnitude of the site characteristics and project scope. The magnitude of the plutonium process decommissioning and the nature of the transuranic contamination defined how technologies could be applied.

2. For the Rocky Flats Closure Project the greatest portion of the work was decommissioning. Decommissioning is essentially the front end of waste processing – it depends on the disposal options and needs to be optimized beginning to end. This includes consideration of how actions will impact the waste type (TRU vs. LLW vs. LLMW), and how packaging impacts transportation and disposal cost.

3. Placing the decisions on technology deployment in the hands of the management directly responsible for execution of the activity ensures that the effort remains focused and accountable, and is more likely to be deployed. This is also an excellent way to engage the workforce and gain their buy-in, since in most cases it is the workforce that uses (or doesn't use) the new technology.

4. Beginning work and placing incentives in place to deploy new technologies to address specific problems has a greater chance of success than creating a new technical system and waiting to begin execution until the system is started. This is the evolutionary vs. revolutionary mindset which Rocky Flats consistently found to be more effective.

5. Identifying the technological approach that would be the winner before the actual work was begun was speculative. For substantial project risks that required TD support, parallel development of competing and/or complementary technologies was most effective.

6. The impact of a number of technical innovations is greater than the sum of the individual innovation impacts, due to synergy, compounding, improvement of schedule, reduction in complexity, etc.

7. Decommissioning is an inherently crude business that requires flexibility and resists elegant solutions. In general Rocky Flats had

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greater success with straightforward technology applications, as compared with highly engineered equipment.

8. Non-manual (typically hydraulic) machinery should be substituted for hands-on cutting whenever possible; however, the need for contamination control often overrides the ability to substitute machinery for people. This supports (up to a point) the need to decontaminate early in the process.

9. During planning, the technical problems become intertwined with other regulatory or management problems; separating the problem types is useful to ensure that the problems being addressed actually have a potential technical solution.

10. The planning process should support the continual reexamination of activities to evaluate how technology improvements could address activity safety and cost, and the management and regulatory issues that need to be negotiated to support those improvements.

11. The ability to deploy a new technology to support a project activity depended on the schedule of that activity in the project. Deployment options range from none – using current proven methods because the implementation time would adversely impact Closure Project critical path schedule – to investing in multiple technologies to allow selection among options for longer-running or future crucial activities.

12. Technology that improves worker safety often leads to improved cost and schedule efficiency, especially when it focuses on improving methods and tools for achieving work.

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