Lessons Learned from US Department of Energy Programs on Decontamination and Demolition, Radioactive Waste Processing and Shipping, and Environmental Restoration of Former Nuclear Technology and Production Sites

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Abstract

The US Department of Energy has contracted for the cleanup and closure of former weapons sites using turn-key, performance-incentive contracts that comprise the complete range of project management, decontamination and demolition, waste management, and environmental restoration technologies. This paper describes several of the technologies developed and deployed in each of the four technical areas, and also the management strategies and systems employed to integrate the various technologies into the overall cleanup plan. Lessons learned from the approaches taken at the Rocky Flats, Hanford, Mound and Savannah River Sites include contractual, regulatory, and technological aspects of the work.

Background

Prior to 1995, the U.S. Department of Energy (DOE) managed the complex of nuclear weapons sites with assistance from Management and Operations (M&O) contractors. The operation of the sites involved the nuclear material missions, the safe and secure maintenance of the sites, and discreet cleanup activities. From the cleanup perspective, the sites consisted of buildings, process and storage equipment, and soil and groundwater regimes, all of which were heavily contaminated both radiologically and chemically. The sites also contained nuclear material of potential future use and nuclear chemical waste, either stored in containers and tanks or held up in the process lines. The decisions about what cleanup activities would be undertaken at a particular site, and when, were made by DOE. DOE decided what technologies and methods would be used, and retained responsibility for the outcomes of the technology decisions. This was a period when very little was known about the nature and extent of the environmental problems at these sites, the problems that were understood had never been tackled before, and the contracting approach was generally appropriate to the time. Technologically, it can be said that the risk of innovative approaches was largely retained by DOE and risk-reward opportunities for the M&O contractors were limited.

Between 1995 and 2000, a new contracting model for cleanup work was introduced to a few of the sites in the weapons complex, beginning with the Rocky Flats Environmental Technology Site. The Management and Integration (M&I) contract awarded to the Kaiser-Hill Company for cleanup work at Rocky Flats contained new requirements, responsibilities, and risk-reward terms. Kaiser-Hill was charged with developing a plan and a schedule for the site security, safe maintenance, and cleanup activities, and supporting DOE in negotiations with the US Environmental Protection Agency (EPA), the Colorado Department of Public Health and Environment, and stakeholder communities, to agree on the level of cleanup and to set milestones for the completion of activities defined so as to show measurable progress on the road to site closure. DOE provided incentives for completion of the agreed milestones on or ahead of schedule. DOE also provided incentives for Kaiser-Hill to complete the milestone activities under budget. Regarding technology, DOE's role changed. In some cases, the technologies were directed by DOE as before; in other cases, technologies were proposed by Kaiser-Hill for approval, and once approved, the performance of the technology was owned by the contractor. Thus it can be said that under the M&I model, a measure of risk-reward for innovation was transferred to the contractor to accomplish DOE-directed cleanup activities, and the incentives were performance-based rather than technology-based.

New Business Model Unleashes Technology

In 2000, DOE established another new business approach in the form of a closure contract, which opened the way for a new technology management concept. Again, the Rocky Flats Site was the first to institute a fully incentive-based business model for dealing with the environmental problems faced by the weapons complex. The Rocky Flats closure contract has since become a model for contracting at contaminated sites that have a similar mission; namely, cleanup and closure. For sites that will have a continuing mission beyond cleanup, such at Hanford, Idaho and Savannah River, the same business model nevertheless applies for the contaminated areas.

The closure contract is open-ended in several important ways. The scope is defined in environmental terms – completion of cleanup – but not in time. Instead, the contractor is working under an agreed target cost and schedule. The contractor shares the reward of scope completion ahead of target cost and schedule, and the consequence of completion over target cost or later than target schedule. That is, the concept of the closure model establishes a multi-year agreed cost/schedule point, and a fee curve in cost/schedule space against which savings or losses are shared by DOE and the contractor. There are no performance measures, and progress is determined by earned value. In the case of the Rocky Flats closure scope, all cost-schedule-technology responsibility and risk was transferred to Kaiser-Hill.

This business model had its intended effect. The incentive to improve operational efficiencies through technology is enhanced in proportion to the level of performance risk-reward transferred to the contractor. A major plus for the closure concept is that productivity (i.e. safety, cost, and schedule improvement) is incentivized by the fee curve set for the entire project rather than individual fees associated with specific activity performance measures. Under the closure agreement, DOE and the contractor *de facto* baseline the needed technology efficiencies up front without having identified and developed the specific technologies for many of the cleanup activities to be undertaken. That is, the technology innovation is implicit in the negotiated cost/schedule target. This is standard business practice in many industries. Year-upon-year productivity improvements are assumed in many company strategic plans, although the technology to deliver the expected results still needs to be developed. Yet this model has only been applied in the nuclear cleanup industry in the last five years as a better understanding of the actual cleanup problems has begun to emerge. Note that it is important to understand the problems, but not the solutions, in order to begin to make real progress. For example, the U.S. EPA Superfund Program for cleaning up contaminated industrial sites began very slowly. One of the reasons cited for this was that studies were carried out to understand the problems at a given site, and then studies were done to determine the solution before the work was begun. In many cases, a better solution was always apparent on the horizon.

Since it is a multi-year fixed-scope but open-ended agreement between, the closure contract enables technology pursuits to be multi-year. This is something that generally did not occur – or at least in some measure was disincentivized – under the M&I scheme since performance measures and milestones were always at hand. Obviously, short term performance metrics have a dampening effect on the full potential of technology utilization. Another technology-liberating aspect of the closure contract model is the absence of a specified work breakdown structure (WBS) and a specified schedule of work activities. The contractor is free to break the work down into whatever activities are deemed advantageous for project management purposes, and to schedule the activities in whatever sequence yields the most efficiency in completing the cleanup mission. Under the M&I and M&O schemes, the DOE, in consultation with regulatory and stakeholder parties, generally directed that the work be sequenced so as to reduce the greatest perceived risk first, the next greatest perceived risk second, and so forth. This may be a good strategy on one level, but for some types of problems, it may complicate or slow the overall project completion. The perceived risk to the public is not always the actual risk, and the effort to reduce a particular perceived public risk may increase the actual worker risk in the process. Completing the cleanup safely, in as short a time as possible, is the best way to eliminate the entire risk to both workers and the community.

The other major plus for the closure contract concept is that programmatic risk assessment (PRA), a key business technology, can be employed. The benefits of using the PRA process for planning and executing a large-scale project include the ability to concentrate resources on problems before they impact the critical path. In the quest to exploit technology as much as possible, the PRA process had the effect of pro-actively identifying technology risks to closure cost and schedule, enabling us to plan alternative technology solutions well in advance of their needed deployment.

The objective of the PRA process, as it applies to a closure project, is to identify the risks to cost and schedule of site cleanup and closure. As the term is used here, risk refers to the uncertainty that the cleanup activities can be accomplished within their planned costs and times, coupled with the impact of an activity overrun on the overall project completion. For every cleanup activity there is an associated cost and duration, whose estimates involve various uncertainties. An essential aspect of the uncertainty is whether the technologies to accomplish the activity will perform as planned. To the extent that the technologies assumed for a particular activity require development and/or demonstration for that application, the uncertainty increases. In the case of a large project like the cleanup of Rocky Flats ($7 billion over 10 years), there are some 40,000 activities, of which more than 10,000 were tracked by the project scheduling system. Typically, the scheduling system is used to determine a project critical path. For PRA purposes, the system is used to calculate a probabilistic critical path rather than a deterministic one. Each activity is entered, not with cost and duration estimates, but with cost and duration ranges. Probability distributions are also entered for those ranges, based on the nature and uncertainty of the estimates for those ranges. The schedule is then run in Monte Carlo mode, yielding multiple completion costs and schedules and a statistical, cumulative probability of each scenario and outcome. There is a critical path, cost and completion date having the highest probability, and there are many "near-critical paths" with associated costs and completion dates. An adjunct to the statistical critical path output is a Pareto Chart, which identifies and ranks the cleanup activities that pose the greatest risks to successful project completion. For high-risk activities that are near-term, management is usually well aware of the issue already. However, for such activities that are scheduled two or three years down the road, resources can be allocated ahead of time so as to avoid or mitigate the risk.

So how can the PRA systems technology be used to exploit the benefits of hard technology – in this sense, the equipment, engineered processes (chemical, mechanical, …), application methods, instrumentation, technical approaches, and knowledge – used in the cleanup operations? As mentioned above, for each cleanup activity (e.g. stripping out a set of contaminated gloveboxes and toolworks, cleaning out a sludge tank, etc.) there are technologies with an element of uncertainty as to their performance. This in turn is factored into the range of cost and duration estimates for that activity. The technology uncertainty can be characterized in terms of its readiness for its intended application, as follows:

- has been proven onsite (Rocky Flats); under actual conditions; performance is known;
- has been demonstrated onsite; under actual conditions; is operationally ready; a contract operator has been identified;
- has been demonstrated at other site(s); under similar conditions
- has completed full scale development and demonstration
- is in development at the laboratory level
- does not exist.

For those cleanup activities shown on the Pareto Chart as high-risk, the cause may or may not be due to technology. If technology is the issue, then we have identified a <u>need</u> for an alternative technology or for an accelerated development and demonstration of the planned technology. The PRA process thus helps us to avoid a "train wreck" ahead of time. If technology is not the issue, then we have identified an <u>opportunity</u> to insert a better technology if it can be found/developed on time. In this case, the PRA process helps us to reduce the cost and/or schedule for site cleanup and closure. In either case, because the closure contract allows for us to reschedule the work as needed, resources can be redeployed to a certain extent until a solution is found and developed. If there is enough time before the problem becomes critical, in the sense that it impacts the closure critical path or near critical path, then the schedule logic is revisited to see if an alternative technical approach to the activity can be introduced. For example, if the problem activity is the shipping of certain containers for disposal and the technology involved is the method of processing the contents, then the solution might be to introduce a new type of container and container-assay instrument rather than to work on a new method of processing the contents.

PRA has become a powerful tool in making decisions about the development and deployment of new technology. To be sure, we are continually looking for innovations that will improve upon safety, cost, and schedule, as well as human resource requirements. In addition to these productivity factors, as mentioned above, there are cases where new technology or a new technical approach is needed to enable a cleanup activity that has no feasible path forward. With these objectives in mind, we can say what the PRA tool helps us to accomplish the following:

- prioritize our efforts on those activities most in need of alternative technology to improve upon the safety, cost and schedule for site closure: "80% of the risk is driven by 20% of the activities";
- schedule our efforts to have the needed technical services ready when the innovation is needed: "Window of opportunity"; and
- support scenario development and alternative technology sensitivity analysis efforts using Kaiser-Hill's WISE Model: "Bottom line impact".

As used here, PRA does not describe the risk that a technology will or will not perform as designed, but rather addresses how significantly that fact or occurrence will affect the site closure. The former is of course a commercial contracting matter, but the decision to deploy that technology does depend on the results of the PRA process. The WISE, or What-if Scenario Evaluation, Model looks at various alternative technologies/technical approaches and possible outcomes to help establish the overall closure project benefit derived from making a change in a given activity or set of activities, the activity logic, and/or the activity sequencing.

One important aspect of the risk-based, probabilistic approach to technology selection, is that multiple technology options for solving a problem must be pursued in parallel. It is not sufficient to try one thing at a time, and wait to see how it works out. Under the risk-reward terms of a closure contract, the one-thing-at-a-time, wait-and-see approach may yield a break-through here and there, but over the hundreds of problems that will be encountered, the overwhelming odds are that the project will overrun. Furthermore, resources must be expended for multiple technologies, not only on the baseline/critical path activities, but on – off-baseline/near critical path activities in order to cover our technology "bets". Inevitably, some technology options will work, others will fail; of those that work, it's often not possible to know which will prove to be the most efficient a priori. Examples of this decision-making approach to technology will be given in the discussions below about decontamination, demolition, and waste shipping.

While it is a standard business principle to assume continually increasing productivity improvement, it is difficult to achieve in practice in a nuclear project with so many unknowns in the project definition, the WBS, and the technology assumptions. The answer is to begin the work with available, proven technology, and make improvements as we go along. The methods for decontaminating a glove box may be good enough to meet the pace of activity in year one, but a better method will be needed for the pace built into the baseline for year two. Fortunately, the PRA model provides a way to manage technology in this environment. The unknowns and technology uncertainties are built into the model, the inputs are updated to reflect progress as well as new problems encountered, and the PRA process is exercised continuously. In this way, the programmatic risk is gradually reduced over the life of the project by the development and deployment of new technologies over the life of the project. In short, the name of the technology game is programmatic risk reduction along the statistical critical path(s).

The technology business model applies both to the contractor and to DOE, since both parties have a stake in the outcome of the technologies deployed. The closure contract transfers the responsibility and risk-reward for technology selection from DOE to the contractor, but only for the cleanup work that is under the control of the contractor. The DOE necessarily retains scope for items that can only be delivered by the government – these include control over timely decision and approval processes, development and availability of government-owned treatment and disposal sites, unique/secure transport containers and services, standards, acceptance criteria, and regulations governing the contractor's activities, and so forth. The DOE also retains a share in the cumulative savings or losses relative to the agreed target cost for site cleanup and closure. The pursuit of new technology is essentially a partnership agreement whereby both DOE and the contractor have distinct, defined scopes that are mutually dependent. An outgrowth of this was an innovative DOE program designed by DOE and the contractor to share the cost and risk of developing and deploying new technologies.

Technology Program for Decontamination, Demolition, Waste Management, and Environmental Restoration

Decontamination and Demolition

In order to address the high levels and varied forms of contamination in building and process equipment at the weapons sites, many problems had to be solved with new technologies and methods. Uncertainties were inherent in that much of the work was being undertaken for the first time, and that the technologies and methods had to be steadily improved every year of the project in order to meet the strict budget and schedule constraints for overall site cleanup and closure. For the decontamination and demolition (D&D) work, two technology strategies were developed and followed throughout. One strategy was to invest resources in many different technologies simultaneously, many of them based on seemingly opposite scientific or engineering principles. Most of the time, there was no way to know in advance which ones would work and which ones wouldn't, nor to know which ones would end up being the more cost and time efficient and for which applications. As it turned out, many technologies failed, some technologies worked, and no single technology proved to be the best way to go for every application. It seems intuitive to say now that what is needed is a tool box with a broad range of tools, but if one listened to what the vendors were claiming, it was not obvious at the outset. The other technology strategy was introduced before; namely, to move forward with whatever D&D technologies seemed feasible at the time, while continually looking to improve upon those technologies or develop new ones and substitute them when they reached the point of demonstrating that they were both effective and more productive than the current method.

Regarding decontamination, we invested in many varied technologies to deal with the challenges presented by both the buildings and the production equipment that had to be decontaminated and properly stabilized for disposal. At the same time, we also invested resources in what might be considered an opposite approach; namely, a range of technologies for the size reduction of buildings and equipment. This is an opposing approach in the sense that the more things were reduced in size, the less they needed to be decontaminated, and vice versa. For both approaches, we knew that some of the technologies might not work, or might cause new problems to emerge. We also expected that a suite of working technologies might be needed before the most cost effective and quickest approach would emerge.

The process equipment that needed to be stripped out of the buildings and disposed of included gloveboxes, machinery, furnaces, chemical reactors, tanks, remote manipulators, piping and valvework, and ductwork, air movers, and filter systems. For the first approach for decontamination, we tried both wet and dry methods. Wet processes included various chemical washes, redox reactions, chelants, and so forth. One interesting example came out of the former plutonium production processes at Hanford and Rocky Flats. This was the use of cerium nitrate in acidic solution. The rationale was that if it was effective for recovery of plutonium for production purposes, it was effective for extraction of plutonium contamination in the process equipment as well. After initial use of this technology proved successful, the method was further refined by developing a way to apply the chemical as an aerosol rather then a liquid. This had the obvious benefit of reducing the volume of byproduct waste generated by the decontamination process. Dry decontamination processes included carbon dioxide CO_2 pellet blasting, nitrogen LN2 abrasion, sponge and soda media, and others. The objective for decontamination was to bring the equipment down from TRU levels of radiation (>100 nCi/g, in the case of plutonium contamination) to low level radioactive waste, or even to free release levels. Low level radioactive waste could be packaged in large sizes for disposal at the Nevada Test Site. Crates and cargo (e.g. "Sea-Land") containers are typical for packaging and disposing of low level waste. By contrast, TRU waste must be packaged in drums (55 gallon) or in Standard Waste Boxes, or SWBs (70 cu. ft.), both specially configured to fit in the TRUPACT II transport container designed for shipment to the Waste Isolation Pilot Plant (WIPP). Thus, decontamination of equipment to low level would reduce the amount of size reduction work needed. For items that could be decontaminated to free release levels, disposal at a municipal landfill was allowed. Of course, this further expanded the options for handling, packaging and transport. However, in many cases, it turned out that the cost of measuring and certifying that an item was eligible for free release exceeded the savings gained via the municipal disposal route.

The payoff for decontamination of process equipment down to low level is three-fold

- Less size reduction work is required. This is first and foremost a safety issue. It is very hazardous to cut up heavy gage stainless steel gloveboxes, pipework, machinery, and the like, particularly when it contains radioactive contaminants.
- Fewer, but larger, containers need to be measured for radioactive content. A significant amount of the cost of packaging, shipping and disposal is due to the regulatory protocols for measurement and certification of the container contents. The fewer the containers, the lower the costs.
- Handling low level materials is simpler. It is far less hazardous to handle materials for packaging and shipping when their radioactivity levels have been reduced from TRU to low level.

As indicated, the decision to decontaminate various types of process equipment clearly takes into account not only the decontamination work, but the fact that the low level and TRU pathways have very different sets of container packaging requirements, different measurement, instrumentation, and certification requirements, different transport requirements, and different disposal sites with different waste acceptance criteria. For TRU wastes, the container options and geometries are limited and prescribed in much greater detail. For low level wastes, the container size is limited only by the ability to accurately measure the contents in terms of hazardous and radioactive constituents. Therein lies another opportunity for technology innovation along the pathways of the decontamination approach to D&D.

Early in the project at Rocky Flats, in order to push the limits on the container size for low level waste, we had a system developed to assay the radioactive contents of approved low level waste shipping crates (up to ~100 cu.ft.) with a precision and accuracy to meet the disposal site acceptance criteria and the U.S. Department of Transportation (DOT) shipping criteria. At the same time, looking further down the road for the next quantum step in productivity, we commissioned a feasibility study for developing an assay system for cargo containers. On a parallel track, we developed in-house, a measurement approach that was completely different – a statistical measurement based on multiple spot readings of radioactive intensity, designed to meet a Nuclear Regulatory Commisssion (NRC) criterion for a low level category known as Surface Contaminated Object (SCO) waste. For this purpose, we had to modify existing instruments so that they could reliably measure at levels up to 480×10^6 dpm/100 sq.cm. and develop the application methods and software systems to convert the spot readings into a qualified ship/no-ship decision. It was easier to use the SCO system on the floor, while decontamination work was in progress, than to find later that a container of packaged waste equipment could not be shipped for disposal.

The SCO toolbox also enabled the boundaries of productivity to be expanded in a new direction – the size of the container. Since it would no longer be necessary to assay the container the old way, the only limit on the size of the object to be shipped for disposal was the size that could be transported. We began to work with the coatings industry to find a way to wrap large pieces of equipment as-is, in such a way that they would meet all the performance requirements of a robust container. A method was developed that combined wrapping with an overcoat of polyurea that could be sprayed on. This equipment-package-container could be described radiologically as a self-contained waste. The bottom line for this approach was that decontamination and measurement could be integrated on the floor, and the amount of size reduction work could be minimized. One of the first examples of our combined decontamination-measurement-packaging technologies occurred when when we shipped three large pieces of furnace and machining equipment, one of which measured 25x10x9 ft. and weighed 150 tons. Considering the worker hazards and time required to try to size reduce such items, even at a low level of radioactive contamination, this is truly a break-through innovation.

Not every piece of equipment could be decontaminated to low levels. The contamination levels might be too high and/or too penetrating, for example. Or the equipment configuration might preclude access for the decontamination method to work, even when the aerosol technique was applied. These items had to be packaged and shipped as TRU waste, thus requiring that they be size reduced to fit into drums or Standard Waste Boxes (~6x3x4 ft). Obviously, we knew that bigger-and-faster is better when it comes to sizing, packaging, measuring and shipping.

Bringing process equipment at TRU levels down in size to drum or SWB scale heightened the need to find safer yet more productive methods of cutting than conventional tools like sawzalls, nibblers, and such mechanical devices. The plasma torch had long been in use for welding, and to some extent cutting, and offered much higher cutting speeds with the materials of construction found at the weapons sites. Techniques and adaptations were developed to deal with fire hazards associated with gloveboxes and contaminants under high temperature, contain and control the particulate dispersion, and provide the workers with safe standoff yet improved control for plasma cutting. For large items such as tanks with organic/solvent residues, water jet cutters were deployed, again with appropriate adaptations for remote control. An integrated pipe cutting –with-containment method was developed for the radioactive contaminated process lines, and the method was modified and used on a larger scale for both radioactive and beryllium contaminated ventilation ducts and plenums. Other cutters, such as oxy-gasoline, magma/phosphorous, jig-saw and reciprocating wire saws, etc., were tested and costed out for the many potential applications, and deployed where appropriate.

Innovation in the size reduction operations was not enough; we also needed to move to larger containers. The reasons were the same as the three reasons given above for low level, but all the more urgent for TRU levels of contamination. The drum was the only container for which a certified measurement system was available. While the WIPP disposal site could accept an SWB, there was no instrument that could assay its contents to meet the WIPP specification. Items need only be reduced to a 4-foot dimension to fit in an SWB, whereas a drum could only hold items of ~1 foot dimension. The potential was there to reduce the hazards and the labor of size reduction by an order of magnitude. We prepared a concept specification for a new generation assay instrument and commissioned the development of what came to be known as the SuperHENC, or high efficiency neutron counter with advanced analytical software, to measure the radioactive contents of an SWB. This proved to be another break-through technology, providing a quantum leap in the D&D and waste shipping of TRU materials.

It was not possible to know in advance whether the technologies developed along the decontamination and size reduction pathways would deliver the needed cost and schedule reductions. Based on the types and quantities of process and storage equipment to be dispositioned within the closure contract cost/schedule target, the PRA process indicated that it was prudent to develop a future generation, higher production technology known as the Remote Operated Size Reduction System (ROSRS). This was a high-through-put, self contained, centralized size reduction system, capable of continuous service for all buildings at the Rocky Flats site. It was completed and successfully passed the prescribed acceptance tests on time to assume its needed duty, but by that time, the decontamination-measurement-packaging pathway known as the SCO toolbox was outperforming all expectations. This meant that less TRU level size reduction work would be needed. The production reached through various stages of improvement in cutting and containment systems, combined with development and improvement in the assay and shipping systems, would be sufficient to meet the site closure schedule. Therefore the ROSRS system was not deployed. Yet it was a lesson in prudent risk management. Had we not invested in and developed this technology on a parallel track, had we waited to see how well the “decon-to-SCO” technologies worked, then we could not have recovered our closure schedule in the event decon-to-SCO fell short. This strategy could be called "hedging your bets" in the world of technology.

After the process equipment is deactivated and stripped out of the buildings, by either pathway, we come to disposition of the contaminated buildings. The strategy and work plan is similar to the approach described above. The toolboxes differ, but the two basic pathways are still followed; namely, decontaminate and then demolish the "clean" buildings by relatively aggressive methods, or, size reduce the "hot" buildings by more controlled methods and package for shipment to a disposal site for radioactive waste. As applied to buildings, the operations occur one level down from the process equipment application. That is, buildings are either dispositioned as free release or as low level material, whereas process equipment is either dispositioned as TRU or low level material. There are exceptions, but this was found to be the general case, for economic reasons as discussed above.

Again, multiple technologies were used to decontaminate floors, walls, and ceilings. The materials of construction (reinforced concrete, block and brick, steel, asbestos), the construction design (wall thickness, secondary walls and ceilings, epoxy, PCB, and lead coatings, configuration/access), and the nature of the contamination (radionuclides/ concentrations, acidic or fire/smoke penetration, solvents) all affected the selection of technology. Besides conventional tools, technologies deployed included purpose-built hydrolasers, concrete shavers, remote-controlled hammers, and diamond wires configured to shave wall surfaces rather than cut through walls. These in turn prompted the development of new technology to control the extracted radioactive materials and fugitive particulate. For wet material, a low-tech, high efficiency, skid-mounted water purge and recycle system was deployed. For dry material, a "vac-n-ship" system was developed to integrate the particulate control with an approved, sealed, high volume (1300 cu.ft.) shipping container. This eliminated a hazardous transfer operation between the collector and the shipping container, and increased the scale of decontamination operations on the collection end (shipping box vs. drum scale).

Building demolition (aggressive) or size reduction (controlled), referred to above, each involved some new techniques or new applications of old techniques. For buildings that had been decontaminated to free release levels, many were demolished using conventional wrecking equipment and water spraying for dust control. In some cases, we were able to work with controlled explosives techniques. As might be expected, these cases were always unique for the industry because of the "nuclear grade" construction design and materials that went into these buildings. One interesting method proved to be very useful for some steel reinforced concrete buildings – harmonic de-lamination. The lattice structure of the rebar was studied, using as-builts and metal mapping techniques, and calculations made to determine its resonant frequencies. Explosives were then set to elicit a maximum harmonic response, which in turn loosened the concrete from the steel. This technology is referred to as "sonic shake-down." For demolition of radioactive buildings, less energetic methods are needed, and partial building dismantlement and containment is the general rule. A water spray is undesirable due to dispersion control and waste generation issues. Instead, a method was developed to create a dense blanket of fog. For this, snowmaking equipment was adapted for use with appropriate water-agent mixtures and droplet sizes to achieve the needed control for these applications.

Increasing productivity in the disposition of buildings, just as with the disposition of process equipment, required continuous leaps forward in the technology for measuring radioactive contamination as applied to the building structure, configuration, and materials. The area to be measured for D&D work planning, for monitoring progress, and for final survey was in the tens of millions of square feet. There was no way to accomplish this with the existing technology. We worked with the instrument vendors to improve the sensitivity and accuracy of measurements taken on-surface, under-surface, and through surface barriers/layers/coatings that had been originally designed and installed with the intention of *shielding* the radiation. As each new generation of instruments came on line, it was immediately deployed even as we launched the development of the next generation of new-and-improved versions. It turned out that we needed, and did develop, arrays of detectors that could simultaneously identify and quantify multiple decay products, cover larger areas faster, and reach more parts of the work modules and building structure, and employ ever more remote operation capability in the process. To support the improvements in detection apparatus, we also had to develop the software, data read-out, and documentation systems to record, map, and report the information needed for our D&D decision-making and the regulators' approvals in as near real-time as possible.

Waste Management and Environmental Remediation

In order to illustrate how the business systems and other technology program approaches were put into action by the CH2M HILL companies at DOE sites, the D&D work was described above in some detail. The strategy and lessons learned were very similar for the work of waste processing and shipping and environmental remediation. Following are a few examples in each of these areas.

To treat a very wide range of waste types, including high level waste, TRU waste, and low level waste, both radioactive and mixed with hazardous chemical constituents, it was necessary to move forward on many fronts at the same time. Even within a single category of wastes, there were of course many waste streams having characteristics that required different processes. So once again, the "divide-and-conquer" approach was taken. Along every pathway, we would always seek the simplest and most versatile process train. At the same time, we would engage the regulators to find alternatives that would meet the intended performance standards where the technology-based regulation might otherwise mandate a method that was technologically and/or economically infeasible.

For low temperature stabilization of low level wastes at Rocky Flats, we explored various grout, ceramic/mineral, and polymer formulations. For versatility, we looked for formulations that could handle the widest range of waste characteristics. We also looked for the greatest efficiency in terms of final treated waste volume. Trade-offs between these were required. For low activity wastes derived from the high level waste tanks at Hanford, we studies diverse technologies in parallel. These included both thermal processes such as in-container vitrification, and steam reforming, and non thermal processes such as grout and ceramic/mineral formulations. Even as these investigations and trials were undertaken, we began to develop measurement technology either to avoid the need for processing or to expand the options for processing and/or packaging and shipping. For example, by measuring certain TRU wastes more accurately, using high resolution gamma assay techniques, we were able to reclassify them as low level wastes. Some examples of increased productivity in packaging and shipping D&D-generated wastes were described in the preceding section.

For environmental remediation, again we worked on many fronts simultaneously. We looked for a combination of technology and regulatory improvements, since these are very closely linked. For groundwater cleanup, we designed passive barrier and reactive media systems so as to minimize the need for long term monitoring and maintenance as would be required by conventional pump-and-treat systems. For the more difficult geologic conditions, we explored passive, in-situ chemical and bio-treatments designed to promote natural attenuation. Methods were deployed that would clean our buried process waste lines to avoid excavation which in many cases causes more exposure to workers and the public over time. Such remediation work was undertaken in parallel with, rather than subsequent to, environmental and public health risk assessments needed to establish a final end-state definition. The performance standard in terms of population exposure had to be translated into specific residual radioactivity levels to be allowed, by location and depth, after site closure. These determinations took years of study, and included detailed analyses of the isotopic compounds in question, the migration chemistry, and statistical models of the source terms, vectors, and post-closure site end-use scenarios.

Along with these technological advances, it was again clear that a comprehensive state-of-the-art measurement, data analysis, and decision making system would be needed that involved the cleanup contractor, the DOE, and all other approving agencies and the stakeholder community organizations. As Rocky Flats is the first of the sites employing the new closure model, the Remedial Action Decision Management System (RADMS) was developed there for deployment by Kaiser-Hill. Without this technology, it would have been impossible to execute the conventional field sampling and analysis, interpretation, staged-iteration clean up, acceptance review cycles, and multi-party decision-making required to close the site within years of the target schedule.

Summary Lesson

In brief, the lesson has been to push forward on all technology related fronts and keep pushing even as solutions to the problems are found. What was learned was that today's solution was only good enough for today, but not good enough for the needed productivity tomorrow. It also has become clear that one cannot wait for the better solution on the horizon. Since there will never be enough money and time to undertake the project as it is conceived in the present, it is necessary to make progress with the technology at hand while pursuing the improvements that will be needed to achieve the targeted budget.

What we found was that the estimated cost of cleanup and closure would continually escalate until the work was actually undertaken. With the right contractual model, the estimated cost and schedule could actually be reversed. For the Rocky Flats Closure Project, reengineering (deploying new business systems) and technology (deploying new processes, equipment, instrumentation, and approaches) added up to a reduction in the cost from $37 billion to $7 billion, and a reduction is schedule from 65 years to 10 years. Closure is now expected by the end of 2005, fully two years ahead of even our own projection five years ago when others thought is was not possible.