LESSONS LEARNED AND PRESENT DAY CHALLENGES OF ADDRESSING 20th CENTURY RADIATION LEGACIES OF RUSSIA AND THE UNITED STATES

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Abstract

Decommissioning of nuclear submarines, disposal of highly enriched uranium and defense plutonium as well as processing of high-level wastes are among the most challenging issues of addressing radiation legacy of the 20th century. USA and Russia are the two primary countries that have to deal with the challenge and where most of the fissile materials to be processed are concentrated, nuclear fuel and high-level radioactive waste are stored, and multiple industrial sites and nuclear weapons production facilities are located. In the US, CH2M HILL is managing two of the most important nuclear projects being conducted by the US Department of Energy at the Rocky Flats Environmental Technology Site and at the DOE Hanford Site (177 underground tanks at this site contain 60 percent of the United States' high-level radioactive wastes). Within the framework of the Russian Federal special program "Radioactive Waste and Spent Nuclear Materials Management, Utilization and Disposal for 1996–2005" works were carried out on the Karachai lake covering with soil, highly-active radwaste vitrification and fractionation at the "Mayak" combine.Currently there is a discussion of launching joint Russian-American initiatives including comparative studies of environmental and public health impacts from high-level waste vitrificaiton and plutonium stabilization processes in Russia and high-level waste removal from tanks in the USA and of continuing comprehensive research with the RADSITE project (USA, European Union, Japan, China and India) using coordinated approaches in 2000-2003. This paper presents comparative studies, technical approaches, and regulatory strategies to address the challenges of managing and closing highly enriched uranium, plutonium, and high level waste sites.

1. INTRODUCTION

The decommissioning of nuclear submarines, disposal of highly-enriched uranium and weapons-grade plutonium, and processing of high-level radioactive wastes represent the most challenging issues facing the cleanup of 20th century radiation legacy wastes and facilities. The United States and Russia are the two primary countries dealing with these challenges, because most of the world's fissile inventory is being processed and stored at multiple industrial sites and nuclear weapons production facilities in these countries.

As part of the Russian Federation, Federal Target Program-Radioactive Wastes and Nuclear Materials Handling, Recycling, and Disposal in 1996-2005, an effort was undertaken to backfill Lake Karachai and to vitrify and grade high-level wastes at the Mayak Industrial Association.

ARRICT

ARRICT (All-Russian Research Institute for Chemical Technologies) is the Russian Nuclear Energy Ministry's leading institute to design technological processes and equipment for comprehensive management of radioactive, rare, dispersed and noble metals. The work ranges from mineral exploration, production of ore concentrate and hydrometallurgical processing to production of pure substances in the form of metals or oxides.

The primary areas of expertise include the development of:

- Methodologies to explore deposits and analyze uranium geostructural elements of the earth crust; and mineralogical surveys of the uranium deposits;
- Scientific guidelines and technologies to process rare-earth/rare-metal composites;
- Chemical and technological characterization of fluorine, uranium fluorides and radionuclides in the nuclear fuel cycle;
- Production of high-purity metal oxides and ceramics for nuclear technologies (including the development of environmentally safe technologies to produce ceramic fuels for nuclear power stations) and microelectronics.
- Technological principles of environmental protection, including the development of environmentally sound technologies for radiochemical processing of those raw materials and wastes that contain natural or artificial radionuclides; technological, technical, scientific and informational support to environmental activities at the nuclear facilities.

CH2M HILL Companies, Ltd.

CH2M HILL is a global project delivery firm providing integrated services to public and private clients in the fields of energy and nuclear management, water, environmental management and site restoration, transportation, industrial facilities, and related infrastructure. CH2M HILL's services encompass all phases of project development and delivery, from planning and financing through design, construction, operations and maintenance, and long-term sustainable development. Through a global network of 153 offices and more than 10,000 professional staff world-wide, CH2M HILL provides local resources to clients wherever they operate.

CH2M HILL is currently managing two of the most important nuclear projects being conducted by the U.S. Department of Energy (DOE). At the Rocky Flats Environmental Technology Site, CH2M HILL is directing the first environmental cleanup and closure of a former U.S. DOE nuclear weapons production site. At the DOE Hanford Site, CH2M HILL is implementing a strategy to eliminate the hazards and public health risks associated with storing millions of gallons of high-level radioactive liquid waste.

2. TECHNICAL ACCOMPLISHMENTS

2.1 Lake Karachai Remediation

Since 1951, Lake Karachai, a natural drainless reservoir in Russia, was used to stockpile liquid mid-level wastes. During the period of active use, a total of 120 million curies were discharged into the lake. In 1988, a phased project to eliminate the reservoir began with confining radioactive bottom sediments into box-shaped reinforced concrete blocks. The lake was then filled with porous material capable of absorbing inflow of groundwater during the periods of high water-level. The final phase of the project involved filling the lake with rock. This remediation work resulted in a reduction of the average surface area of the lake from 360,000 square meters in 1991 to 100,000 square meters in 1999, thereby substantially decreasing aeolation of radioactive aerosols from the surface and water front. Over 85% of radioactive wastes have been immobilized in the backfilled part of the lake. Currently, the work is approaching its completion stage.

Since 1992, an investigation has been underway to determine patterns of contaminated water migration originating in Lake Karachai. This investigation involved a detailed survey of the geological structure of the Mayak site and determination of the lithosphere structure. Based on the results of the survey, short-and long-term forecasts of pollution migration were made, and sites for underground laboratory and future repositories for radioactive wastes are being selected.

2.2 Mayak Vitrification Project

Personnel at the Mayak Industrial Association have implemented a technology to vitrify high-level liquid wastes in EP-500 ceramic kilns. The aggregate radioactivity of the processed wastes has reached 300 million curies. Borophosphate glass has been developed and tested for further use in vitrification of high-level wastes. A scheme has been designed to prepare high-level wastes for inclusion in borophosphate glass. An additional industrial facility has been proposed to enable the processing of different types of high-level wastes as borosilicate and quasi-mineral compositions. Within the next ten to twelve years, Mayak personnel are planning to implement a technology to grade high-level wastes and to extract caesium, strontium, transuranium, and rare-earth elements to process all nitric acid solutions produced by the facility. I In addition, the plant will be processing and vitrifying the entire range of high-and mid-level wastes generated at Russia's radiochemical and radioisotope plants.

2.3 Hanford River Protection Project

CH2M HILL is managing 200 million litre's of highly radioactive and hazardous waste stored in 177 underground tanks at the U.S. DOE Hanford Site. This liquid waste represents 60 percent of the United States' high-level radioactive waste inventory. The ultimate goal of this project is to vitrify the waste into glass logs to be stored in a long-term underground repository. CH2M HILL is removing liquid waste from older single-shell tanks some of which have previously leaked, minimizing the risks associated with flammable gas build-up in certain tanks, and resolving significant safety issues to remove nearly 20 tanks from the U.S. Congressional watch list of dangerous tanks. These risk reduction activities involve rotary core sampling of hard-caked waste deposits, tank sluicing and sludge removal for high heat tanks, a comprehensive upgrade of existing tank farm infrastructure, and technology deployment and new equipment installation for retrieval and transfer of the liquid waste to a vitrification facility.

H2M HILL is addressing the nation's legacy of nuclear wastes by creating first-of-a-kind approaches to deal with the challenges. For instance, the C-106 tank at the Hanford tank farm is a single-shell tank that has been a safety concern for several years because of its high heat content. The physical characteristics of the waste in this tank result in both liquid and solid wastes. There was sufficient heat content in the tank that if left alone, the temperature would rise, which had the potential to cause a catastrophic failure of the tank. CH2M HILL managed the temperature by adding water to the single-shell tank for evaporative cooling and installing a sluicing system in the tank. The waste was sluiced to a safer double-shell tank, eliminating the risk the tank once posed.

CH2M HILL also resolved the issues of the SY-101 double-shell tank, once considered the most dangerous tank in the DOE complex. This tank generated and retained significant quantities of flammable gas made up of hydrogen and ammonia, which presented the potential for explosion. To remedy the situation, a mixer pump was installed in 1993 to stir the tank waste, which resulted in the safe and gradual release of the built up flammable gases. Recently, the tank began retaining additional quantities of flammable gas, demonstrating that another solution was needed. Having studied the tank's physical properties, CH2M HILL understood them well enough to suggest that diluting the waste with water and transferring it to other tanks would resolve the issue. Now that this work is complete, the tank is no longer considered the most dangerous tank in the DOE complex.

2.4 Rocky Flats Closure Project

CH2M HILL is deactivating, decommissioning, decontaminating, and demolishing more than 700 facilities totalling 325,150 square meters of former nuclear weapons production facilities at the U.S. DOE Rocky Flats Site. For this ten-year project scheduled to be completed by December 15, 2006, CH2M HILL is applying plasma arc equipment dismantlement techniques, pipe-and-go contaminated waste packaging, and inner tent worker protection technologies. In addition, several methods have been developed to process and package more than 115,000 kilograms of plutonium residue waste. Over the course of the project, CH2M HILL will dispose of more than 200,000 cubic meters of transuranic and low-level waste and will remediate more than 130 individual areas of soil and water contamination at the site.

Rocky Flats stores more than 115,000 kilograms of plutonium by-products of past nuclear weapons production operations. Called residues, these wastes must be stabilized and/or repackaged prior to offsite shipment. Most of the Rocky Flats residues will be disposed at the DOE Waste Isolation Pilot Plant in Carlsbad, New Mexico, a long-term radioactive waste repository. Residues are in the form of salt, ash, and wet and dry combustibles. One device that had an incredible effect on the residues program was the development and use of the pipe overpack component. Designed at Rocky Flats, the pipe overpack component is a .635-millimeter thick stainless steel pipe that holds two waste containers. The pipe is packed into a 208.197-liter drum and shipped for disposal. Because of the shielding the pipe overpack component provides within the waste drum, many residues do not require the stabilization once necessary. This technology has reduced worker exposure, increased safety, and saved valuable time and cost. To date, CH2M HILL has processed and packaged more than 60,000 kilograms of Rocky Flats residues.

CH2M HILL applies the latest and most effective technologies for decontaminating nuclear facilities and reducing the hazardous waste volume generated by decommissioning activities. Many nuclear buildings consist of reinforced-concrete walls that are several feet thick. These thick walls add a layer of complexity to the deactivation and decommissioning process. In late 1999, CH2M HILL directed the deactivation and decommissioning of a large plutonium building at Rocky Flats. The building cluster included Building 779, a former nuclear weapons research and development facility, and its surrounding support structures. In all, nearly 1 hectare of building space was deactivated, decontaminated, and demolished. CH2M HILL used innovative techniques including a high-pressure water spray called hydrolysing to remove surface contamination from concrete and a special survey machine that can assess 1.829-meter-wide stretches of wall or floor at a time. To determine that the building was ready for demolition, CH2M HILL performed more than 2 million separate radiation measurements.

3. TECHNICAL CHALLENGES

3.1 Technology Challenges

For the Hanford River Protection Project, many technology hurdles must be overcome to achieve the safe, compliant, and cost-effective retrieval, vitrification, and long-term storage of the high-level radioactive waste in the massive Hanford tank farm. CH2M HILL is continually collaborating with several United States technology vendors to identify and deploy technology. Through participation in the October, International Conference and other initiatives, CH2M HILL hopes to exchange technology information and foster a working relationship with the Russian Federation to further the technological development required to deal with the radiation legacy of the 20th century.

The Hanford River Protection Project requires technology or technical process development for the areas presented below.

Large-scale Vitrification Systems

Vitrification systems are being successfully demonstrated at DOE sites in the United States and commercially in Europe. The unique challenges at Hanford relate to designing scaled-up units that can handle Hanford's large volume of radioactive wastes. Pre-treatment technologies involve ion exchange systems to remove ceasium-90 and technetium-99, precipitation systems to remove strontium-90 and transuranic, and ultra-filtration systems to separate solids from aqueous wastes.

Curie Count

Currently, techniques to assess the amount of residuals left in a tank exist. However, techniques must be developed to determine the amount of curies left in a tank. CH2M HILL will need this capability within a few years.

Sludge Mobilization Methods

An enhanced sludge mobilization method is needed to retrieve sludge that is beyond the effective cleaning radius of a baseline pair of long-shaft mixer pumps. The objective for this method development is a small system that can be installed in a tank along with a mixer, when mobilization is required to retrieve remaining sludge in a tank.

Variable Level Suction Transfer Pump

A variable level suction transfer pump is needed to draw waste from pre-selected levels that range from the surface of the waste to within 25.4 centimeters of the bottom of a tank, because of stratified waste layers. Currently, transfer pumps achieve variable suction levels by using a flexible hose controlled by a tether cable. This design cannot be operated simultaneously with mixer pumps because of hose instability.

Pressure and Velocity Determination

Inter-area transport lines for particulate slurries have become plugged in the past due to particle settling, phase changes, or reactions accompanied by precipitation or gel formation that occurred during transport. Information to predict pressure drop and critical transport velocity of wastes with known properties is required to ensure that wastes can be safely transported without risk of plugging. To minimize the dilution required to modify waste properties, methods to predict the effect of dilution, washing, or leaching on the slurry properties is also required. Dilution both increases the volume of the waste and has negative implications for tank waste management both from a space perspective and for settling and separation of solids. Waste compatibility is also an issue in the case of blending of wastes from several simultaneous or sequential retrievals.

Waste Solubility

Information is needed on the solubility of various components in the complex solid and liquid matrices of the Hanford tank wastes, especially those associated with sludge's. CH2M HILL needs to predict when solids will precipitate or when gels will form in retrieval, wash, and leach solutions. Empirical water wash and caustic leach data from enhanced sludge wash testing of tank sludge samples and other data from dissolution testing of saltcake samples must be supplemented.

Precipitation Model

Predicting the precipitation of solids in a complex, concentrated brine requires a suitable model and a well-designed set of data from which model parameters can be obtained. Although the identity and approximate quantities of major and minor chemical components in the Hanford tanks are fairly well defined, there are inadequate fundamental experimental data to support an adequate predictive model, and there has been inadequate use of existing data. The solubilities of solid phases in high-ionic strength brines that approximate subsets of the actual Hanford chemical systems need to be measured to include: 1) determine equilibrium constants and 2) extract electrolyte model parameters describing the behaviour of sparingly soluble compounds.

Contaminant Release Compliance

In order to meet the contaminant release specifications for the disposal of low-activity tank waste, radiocontaminants are physically trapped in glass. However, only a few of these radioelements drive the performance assessment. If key radioelements could be chemically trapped after release from glass, the performance of the waste disposal system could be significantly improved. Hydraulic properties of getter materials (original, loaded, and discharged) need to be measured to fully understand waste disposal performance in the presence of getters. The use of getter materials in the DOE Savannah River Site's disposal of the saltstone waste was an important consideration in the approval of that site's tank waste disposal strategy.

Sluicing Systems

Improvements in sluicing technology have been made since past practice sluicing was performed at Hanford for tank waste retrieval. A better understanding of these improvements and how they compare to past practice sluicing is needed to optimize waste retrieval operations. A direct comparison between past practice sluice nozzles and current industrial nozzles needs to be performed to provide the most effective design to support high-level waste feed to the vitrification plant. A comparison between past practice pumping systems and current improved pumping systems should also be completed. The comparisons must provide a clear quantitative analysis of the ability of each nozzle and pump type configuration and the ability to move different waste types.

Leakage Detection Systems

The use of past-practice sluicing for single-shell tank waste removal involves the addition of liquid to tanks and, therefore, increases the potential for waste leakage to the environment. Leak detection methods are needed that can signal and quantify a leak from a tank when only a small amount of waste has been released.

CH2M HILL must develop leak detection methods that will work in dry soils, be robust enough to handle a range of contamination levels, and will provide real time monitoring to support corrective actions during operations activities.

Vadose Zone Characterization

Alternative technologies to conventional core drilling for characterization of the vadose zone that are fast, economical, and minimize intrusion to the vadose zone are needed. These technologies should: 1) qualitatively and semi-quantitatively screen the soil column for contaminants of potential concern and in so doing identify zones of contamination in the tank backfill material and vadose zone in tank farm and 2) obtain soil samples at selected depths for confirmatory laboratory analysis. The technology must be capable to detect metal pipes and obstructions and selectively seal any borings introduced into the soil column to eliminate any potential pathway for contaminant leakage to the aquifer. Technology to verify the quantity and extent of contaminants leaked to the vadose zone in the tank farm will reduce the uncertainty associated with estimates of the radionuclide and hazardous chemical inventory in the tank farm soils. This information is key input to the performance assessment model and the assessment of alternatives for retrieval and tank farm closure.

Contaminant Containment

Although no tanks are currently leaking, 67 of the 149 single-shell tanks at Hanford are known or suspected leakers. Retrieval of waste from these tanks will incur additional risk from leakage. In addition, waste that has been retrieved will be processed, vitrified, and disposed in solid form. Based on past analyses, this waste may add radionuclides to the soil column. For example, the performance assessment activities supporting the disposal of vitrified low-activity waste identified technetium-99 and selenium-79 as the radionuclides that contributed most significantly to long-term risk. If these key radioactive elements could be trapped or immobilized in the waste matrix, disposal facility, closed tanks, and/or the soil column, the risk to human health and the environment could be significantly reduced. It is proposed that sequestering agents be deployed as a permeable flow-through (reactive) barrier to attenuate the migration of these contaminants and reduce the risk. In the case of contaminated soil, the reactive barrier will be placed using conventional emplacement technology, e.g., slant drilling, etc. For the vitrified waste and for tank closure, it is proposed that the getter could be placed inside the facility.

3.2 Regulatory Challenges

Russian and United States environmental programs are governed by regulatory agencies that oversee the work performed to cleanup the radioactive legacy of the 20th century. Both countries' programs are briefly described below.

Russian Federation

The Russian Federation Nuclear Ministry's environmental and sustainable development programs and action plans are targeted to preserve fresh water quality, implement safe and environmentally sound practices for handling toxic and radioactive wastes, eliminate radioactive contamination, and foster sustainable development of Russian regions. These programs and plans are implemented on the basis of the most advanced technologies and reliable baseline environmental information collected and accumulated in various information systems.

In the Russian Federation, radiation legacy research included the development of information systems to collect and analyze reliable data that is important to assessing public health and environmental impacts of radioactive wastes. The Russian Federal Nuclear Ministry, Russian Academy of Sciences, Russian Federal Defence Ministry, Russian Public Health Ministry, Russian Federation Ministry for Natural Resources, Russian Federation Committee for Meteorology, and Russian Scientific Center – Kurchatov Institute worked together (ARRICT coordinated the effort) to develop the Radleg Information System. From 1995 to 2000, these organizations performed a comprehensive analysis of Russia's radiation legacy and created the system with a geoinformation center as part of International Science and Technical Center Project No. 245. A panel of Russian experts representing 25 organizations will use the Radleg Information System to evaluate environmental hazards and public health risks associated with the following:

- nuclear submarine decommissioning (unloading, transportation, and storage of irradiated fuel; dismantlement and removal of nuclear submarine parts; and handling of radioactive wastes)
- high-level uranium processing (processing into low-level uranium [to be used as fuel at nuclear power stations], transportation, and storage)
- weapons-grade plutonium processing (irradiation in light-water and fast reactors; production of MOX fuel; processing, transportation, and storage of MOX fuel; and waste handling, transportation, and storage).

United States

Throughout much of the industrial production history of the United States there were few laws regulating waste management and environmental protection. In the 1970s and 1980s new environmental laws governed waste management, storage, and disposal and environmental emissions. Public awareness and concern for the potential impact of cleanup activities on the quality of life in the Pacific Northwest have lead to significant opportunities for the United States government, the States of Washington and Oregon, and the Indian tribes to discuss and influence the cleanup actions taken.

The National Environmental Policy Act (NEPA) requires United States agencies to analyze proposed actions for environmental impacts as part of the decision process. The State of Washington has a similar law governing agencies overseeing cleanup efforts. In addition, the Clean Water Act; Clean Air Act; Resource Conservation and Recovery Act; Comprehensive Environmental Response, Compensation, and Liability Act; Atomic Energy Act; Nuclear Waste Policy Act; and the Washington State Hazardous Waste Management Act all affect the management, treatment, and disposal of the Hanford tank waste.

In 1986, the U.S. Environmental Protection Agency, Washington State Department of Ecology, and DOE began examining how to bring the Hanford site into compliance with the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act. The Hanford Federal Facility Agreement and Consent Order (commonly referred to as the Tri-Party Agreement) was signed by the three agencies in 1989 yielding a single compliance agreement that set agreed-upon milestones for cleaning up releases of hazardous substances.

While the Tri-Party agreement is the foundation from which the clean up work is conducted, a variety of permits and approvals are required to conduct day to day work performance associated with the cleanup mission. This includes obtaining nuclear safety reviews for any modifications or new work associated with the tank farm system, performing antiquities reviews to ensure that any facilities affected are not considered national treasures, evaluating excavations for evidence of historical cultural significance, and obtaining air and water permits. These varied reviews, permits, and approvals present significant challenges in addressing radiation legacies from the 20th century but are more importantly directed at ensuring that natural resources and the quality of life in the Pacific Northwest are preserved during the clean up mission.

Environmental stewardship is a key element in the closure of the Rocky Flats site which in itself is one of the most important environmental projects in the entire United States. CH2M HILL strives to go beyond compliance to achieve environmental stewardship excellence that encompasses a broad spectrum of activities at Rocky Flats that includes: environmental monitoring; ecology and natural resource protection; natural resource conservation; recycling and waste reduction; environmental compliance; and soil, waste, and building remediation.

A unique regulatory strategy has been developed for Rocky Flats that focuses regulator attention on public protection and worker safety excellence, reducing the site's highest risks first, and removing the entire special nuclear material inventory from the site. CH2M HILL is working in partnership with the U.S. Environmental Protection Agency, the Colorado Department Public Health and Environment, and the U.S. Defence Nuclear Facilities Safety Board to completely eliminate all hazards at the site, demolish all facilities, and return the property to a natural open prairie indigenous to the Colorado area. Soil, water, and building remediation activities at Rocky Flats support the site's accelerated closure goal and are governed by the Rocky Flats Cleanup Agreement. This agreement, signed by DOE, the Environmental Protection Agency, and the Colorado Department of Public Health and Environment in July 1996, provides the regulatory framework for closure with priority given to addressing the most urgent risks first.

4. RUSSIAN / UNITED STATES KNOWLEDGE TRANSFER

Discussions are underway to launch joint Russian-American initiatives to share lessons learned from nuclear programs in Russia and the United States. These collaborative efforts may include comparative studies of environmental and public health impacts from high-level waste vitrification and grading processes in both countries. Comprehensive research will continue between the years 2000 and 2003 on the RADSITE project, which involves a coordinated approach among the Russian Federation; European Union; and the countries of Japan, China, India, and the United States.

DISCUSSION AFTER THE PRESENTATION OF M.J. RENGEL

A.V. BOYTSOV (Russian Federation): Could you comment regarding the use of plutonium in the production of MOX fuel?

M.J. RENGEL (USA): In the United States, a facility for converting plutonium stockpiles into MOX fuel is being designed. Because of its experience at Rocky Flats, CH2M Hill has been involved in the movement of much of the existing plutonium to storage at the Savannah River site, where the facility is to be built.

The Russian Federation will be embarking on a MOX fuel production programme at some time, and CH2M Hill stands ready to assist Minatom in that connection when the time comes.

B.N. GOLUBOV (Russian Federation): What are the prospects for the use of Yucca Mountain as a permanent repository for highly radioactive waste?

M.J. RENGEL (USA): It has not yet been decided that Yucca Mountain will be used as a permanent repository for spent nuclear fuel and other highly radioactive material. We are planning on the basis of the design criteria in place today for the Yucca Mountain facility, to which the material now at Hanford will be moved if the facility is approved.