The US DOE Office of Environmental Management International Cooperative Program: Current Status and Plans for Expansion - 9203

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ABSTRACT

The Department of Energy Office of Environmental Management (DOE-EM) Office of Engineering and Technology is responsible for implementing EM's international cooperative program. The Office of Engineering and Technology's international efforts are aimed at supporting EM's mission of risk reduction and accelerated cleanup of the environmental legacy of the nation's nuclear weapons program and government-sponsored nuclear energy research. To do this, EM pursues collaborations with government organizations, educational institutions, and private industry to identify and develop technologies that can address the site cleanup needs of DOE.

Currently, DOE-EM is performing collaborative work with researchers at the Khlopin Radium Institute (KRI) and the SIA Radon Institute in Russia and the Ukraine's International Radioecology Laboratory (IRL). Additionally, a task was recently completed with the Nuclear Engineering Technology Institute (NETEC) in South Korea. The objectives of these collaborations were to explore issues relating to high-level waste management and to investigate technologies that could be leveraged to support EM site cleanup needs.

The initiatives in Russia and South Korea were aimed at evaluating and advancing technologies to support U.S. high-level waste vitrification initiatives. The work at KRI was targeted at improving the throughput of current vitrification processes by increasing melting rate and/or waste loading. The objectives of the efforts conducted at SIA Radon and NETEC were to evaluate advanced melter technologies to make dramatic increases in waste loading and throughput.
The collaborative effort conducted with the IRL in the Ukraine has the following objectives:

- Assess the long-term impacts to the environment from radiation exposure within the Chernobyl Exclusion Zone (ChEZ);
- Provide information on remediation guidelines and ecological risk assessment within radioactively contaminated territories based on the results of long-term field monitoring, analytical measurements, and numerical modeling of soils and groundwater radioactive contamination; and

- Recommend the development and testing of effective cleanup technologies to reduce environmental and health risks.

In FY09, continued collaboration with the current partners is planned. Additionally, new research projects are being planned to expand the international program. A collaborative project with Russian Electrotechnical University is underway to evaluate Cold Crucible Induction Melter (CCIM) control and monitoring technologies. A Statement of Intent was recently signed between DOE-EM and the U.K. Nuclear Decommissioning Authority (NDA) to work cooperatively on areas of mutual interest. Under this umbrella, discussions were held with NDA representatives to identify potential areas for collaboration. Information and technical exchanges were identified as near-term actions to help meet the objectives of the Statement of Intent. Technical exchanges in identified areas are being pursued in FY09.

INTRODUCTION

The Office of Engineering and Technology has developed a Technology Roadmap and a Multi-year Program Plan to identify technology needs and identify areas for focused research and development to support DOE-EM's environmental cleanup and waste management objectives. The international cooperative program is an important element of the technology development roadmap, leveraging of world-wide expertise in the advancement and deployment of remediation and treatment technologies.

Currently, the international program is working with researchers in Russia and Ukraine and a project with researchers in South Korea was recently completed. The latest results from the current bilateral collaboration projects being implemented by EM in support of the EM accelerated cleanup and closure mission are presented. Additionally, initiatives to be conducted in FY09, resulting in significant expansion of the international program, are also summarized.

IMPROVED ALUMINA LOADING IN US HIGH-LEVEL WASTE GLASSES – KRI, PNNL AND SRNL

Background and Application

The U.S. Department of Energy (DOE) is currently processing (or planning to process) high-level waste (HLW) through Joule-heated melters at the Savannah River Site (SRS) and Hanford. The process combines the HLW sludge with a pre-fritted glass or mineral additives which are subsequently melted. The molten glass is poured into stainless steel canisters to produce the final waste form. Both process and product performance issues must be addressed. The product performance issue relates to the durability of the glass waste form. Process related issues (e.g., liquidus temperature, viscosity, electrical conductivity, and melting rate) ultimately dictate the efficiency and effectiveness of the melter operation.

Recent tank retrieval and blending strategies at both SRS [1] and Hanford [2] have identified increased amounts of high-Al_2O_3 waste streams that are scheduled to be processed through their respective high-level waste (HLW) vitrification facilities. For example, current Hanford projections suggest that the Al_2O_3 concentrations in sludge could be as high as 80 wt% in the waste. The Al_2O_3 has an impact on three main constraints in glass formulation, the increases of Al_2O_3 in glass:

- Promotes the crystallization of aluminum-containing crystals during slow cooling in the canister, which can decrease glass durability
- Increases the liquidus temperature of spinel crystals that can interfere with melter operation
- Has a potential to decrease feed processing rate due to refractory property of Al_2O_3., i.e. slow dissolution into the glass forming melt.

To address these issues, Khlopin Radium Institute (KRI) in Russia, Pacific Northwest National Laboratory (PNNL), and Savannah River National Laboratory (SRNL) have jointly performed the following two studies:

- Matrix crucible tests to develop database and models to formulate glasses for DOE waste streams with high aluminum concentrations (FY06 - FY08)
- Melter testing for SRS glasses representing a projected Sludge Batch 5 (SB5) composition without the implementation of the Al-dissolution process and a projected SB5 composition after the completion of Al-dissolution (FY07 – FY08)
- Scale-up melter testing for Hanford wastes with a selected glass containing 26 wt% Al_2O_3 (FY07 - FY08).

The matrix crucible test results were discussed elsewhere [3, 4]. The melter testing conducted on the SRS and Hanford feeds will be discussed here.

Experimental Melters

Two melter systems were utilized at KRI in support of this study, the Steklo Metallicheskie Konstruktsii (SMK) melter system and the Electricheskaya Pech-5 (EP-5) melter system. The SMK is a batch melter intended for experiments on the rate of melting (by monitoring cold cap consumption) and crystal accumulation (through sectioning of the melt crucible) of simulated HLW glass. The components of the SMK melter system make it possible to provide for a dry or liquid feeding, off-gas treatment, air bubbling, glass product pouring, and vitrification temperature monitoring, with a continuous stirring of the feed. The EP-5 melter is configured for longer-term, continuous feeding and batch pouring. It is equipped with systems and mechanisms that provide for the following: dry or liquid feeding, off-gas treatment, air bubbling of the melt, pouring of the glass product, and temperature monitoring of the melting process.

Melter Testing on SRS Feeds

KRI prepared the sludge simulants in accordance with recommendations provided by SRNL. KRI used two types of simulated sludge for the SRS feeds: which represented a projected Sludge Batch 5 (SB5) composition with (Sludge 1) and without (Sludge 2) the implementation of the Al-dissolution process [5, 6]. Three frits were evaluated for combination with the simulated SRS sludges to evaluate the impact of frit composition on melt rate [7].

<u>SMK Experiments</u>

The results of the SMK runs with the SRS feeds are summarized in Table I. Visual observations of the melter experiments provided some insight into the behavior of the frit-sludge systems. When Sludges 1 and 2 mixed with Frits 503 and 517 (targeting a 35 wt % waste loading) were fed onto the melt surface, the cold cap distributed unevenly, mostly accumulating in the area where the feed entered the system. When the cold cap coverage reached the target 80-95%, mounding of the feed was observed on the cold cap. Melting of Sludge 1 mixed with Frit 503 resulted in a calcinate accumulation in the pour closure rod due to spills of the sludge. Melting of Sludge 1 mixed with Frit 517 resulted in a calcinate accumulation on the crucible wall. The calcinate accumulation did not make it possible to accurately measure the time required for consumption of the cold cap. No calcinate formations were associated with Frit 520. The feed material and the cold cap distributed evenly on the melt surface and the melting process continued as intended. Partial loss of the feed during feeding of Sludge 2 mixed with Frit 520 was experienced due to damage of a hose in the peristaltic pump.

Table I. Results of the SMK Testing with the SRS Feeds

Frit Type	503		517		520	
Sludge Type	Sludge 1	Sludge 2	Sludge 1	Sludge 2	Sludge 1	Sludge 2
Feeding Time (minutes)	195	320	215	260	200	130
Average Feeding Rate (L/hour)	1.03	0.55	0.90	0.67	1.03	0.95
Mass of Glass Poured (g)	1490	1400	1460	1382	1470	1120
Pouring Time (minutes)	35.00	20.00	15.75	11.58	29.00	20.00

The melt rate provided by the three frits was evaluated by comparing the average feeding rates for each experiment. In general, the melt rates for the Sludge 1 glasses were higher than those for the Sludge 2 glasses. For the Frit 503 and Frit 517 glasses, the melt rates differed significantly between the two sludges, while for Frit 520 the melt rates for the two sludges differed insignificantly. Frit 520 provided a fairly high melt rate for processing both sludges. Frit 520 also produced a reasonably homogenous glass when combined with either sludge and was, therefore, selected for processing Sludges 1 and 2 in the EP-5 Melter.

EP-5 Experiments

The goal of the EP-5 experiments was to identify the optimal feeding rate and determine whether a difference in melt rate could be observed between the sludges combined with Frit 520. The evaluation was made by monitoring the cold cap growth associated with a gradual increase of the feeding rate. The initial feeding was performed at a given rate for 30 minutes. If, during this time, the melt surface was not 80-90% covered with the cold cap, the feeding was stopped until the cold cap was consumed. The feeding rate was then increased and the process repeated. The feeding rate was subsequently reduced if the melt surface was 100% covered with the cold cap within 30 minutes. At the completion of feeding and cold cap consumption, the melted glass was held in the melter for one hour to be followed by complete pouring into a collector can.

The Sludge 1 glass was batch poured once (6840 g). The feeding rate ranged from 1.6-2.0 L/hr, with the optimal feeding rate being 1.7 L/hr. The Sludge 2 glass was poured twice (805 g and 4156 g). The feeding rate ranged from 1.4-1.8 L/hr. The optimal feeding rate was 1.6 L/hr. There was no obvious difference in melt rate between the two sludge types.

Table II shows data on the spinel content in the glass from the two EP-5 experiments. The poured glass from the Sludge 1 experiment had a zoned distribution of spinel. The middle part of the glass contained a larger amount of spinel than the upper and bottom parts, which may relate to cooling rate. No spinel was observed in the glass from the first pour with Sludge 2. The spinel content in the glass from the second pour of Sludge 2 ranged from 0.05 to 0.8 vol %.

Table II. Spinel Content in the SRS Glasses Melted in the EP-5 (averages of 3 measurements)

Sludge 1		Sludge 2	
Sample	Spinel Content	Sample	Spinel Content

Location	(vol %)	Location	(vol %)
Top	0.4	Top	0.5
Middle	1.6	Middle	0.1
Bottom	0.2	Bottom	0.3

The results showed varying degrees of spinel formation in all of the glass compositions using both of the melters. Spinels are known to have little influence on chemical durability and, therefore, were not of significant concern. Melt rates were estimated based on the feeding rate that provided optimum cold cap coverage on the melt pool. Some improvements in melt rate were made by tailoring the frit composition for the feeds. Differences in cold cap behavior (flowing of the feed material) were also noted.

Melter Testing on Hanford Feeds

Glasses with Al_2O_3 loading ranging from 25 to 27 wt % to represent Hanford type waste feeds were formulated and tested at a crucible scale. Successful glass formulations with up to 26 wt % Al_2O_3 that did not precipitate nepheline during canister centerline cooling (CCC) thermal conditions and had spinel crystal contents of 1 vol % or less after 24 hr heat treatment at 950°C were obtained. The selected glass, HAL-17 with 26 wt % Al_2O_3, had viscosity and electrical conductivity within the boundaries for adequate processing in the Joule-heated melters operated at 1150° C. This HAL-17 glass was successfully processed using small-scale (SMK) and larger-scale (EP-5) melters. There was no indication of spinel settling during processing. The product glass samples from these melter tests contained 1 to 4 vol% spinel crystals that are likely formed during cooling. The Product Consistency Tests (PCT) conducted on the as-received and CCC samples of product glass resulted in normalized releases lower than the Defense Waste Processing Facility (DWPF) EA glass by more than an order of magnitude.

This study demonstrated that it was possible to formulate glasses with up to 26 wt % Al_2O_3 that satisfy the property requirements and these glasses were processable with Joule-heated melters operated at 1150° C – a roughly 100% improvement over the current 13 wt % limit in Hanford Tank Waste Treatment and Immobilization Plant (WTP) glass. Considering that the cost of HLW treatment is highly dependent on loading of waste in glass, this result provided a potential for significant cost saving for Hanford. The observed glass production rate per unit melter surface area was comparable to the design capacity of WTP HLW melters for the SMK test, but the test with EP-5 melter achieved roughly half of the WTP design capacity. Further testing was recommended to quantify the effect of high Al_2O_3 loading on glass production rate.

Path Forward

Melt rate testing in FY09 in support of SRS will focus on developing an improved understanding of the impacts of B_2O_3 and alkali concentrations in the frit on melt rate using simulated feeds representing with and without the implementation of the aluminum dissolution process. Based on future sludge batch compositional projections, SRNL has developed two nominal sludge compositions representing (on average) both with and without aluminum dissolution flowsheets. These will serve as the basis for follow-on testing, along with a series of revised candidate frits.

As described above, a glass with 26 wt% Al_2O_3 processed at roughly 50% of the design specific rate of the WTP melter. PNNL, under a separate EM-20 program, is investigating the impacts of glass and melter feed chemistry on production rate in Hanford HLW melters. This will result in methods to improve melting rate of high loaded glasses in general, with emphases on the melt rate improvement for high-alumina loaded glasses. The main objective of this task is to demonstrate methods of melter feed formulation for improved melting rate and to quantify the impact of the improved methods. KRI will test the resulting formulations to help further develop the method. This KRI testing will be performed in the EP-5 melter to allow for direct comparison with previous tests.

COLD CRUCIBLE INDUCTION MELTER DEMONSTRATION FOR SRNL WITH SIMULATED SLUDGE BATCH 4 DWPF WASTE – NETEC AND SRNL

Background and Application

Cold Crucible Induction Melter (CCIM) Technology is being considered as a possible next generation melter for the DWPF. Initial and baseline demonstrations that vitrified a Sludge Batch 4 (SB4) simulant at a waste loading of 50 wt % (versus about 34 wt % in the current DWPF melter) were performed by the NETEC in South Korea. This higher waste loading was achieved by using a CCIM which can run at higher glass processing temperatures (1250º C and higher) than the current DWPF Melter (1150º C). Higher waste loadings would result in less canisters being filled and faster waste throughput at the DWPF. The main demonstration objectives were to determine the maximum melt rate/waste throughput for the NETEC CCIM with a Sludge Batch 4 simulant as well as determine the feasibility of this technology for use in the DWPF.

CCIM Test Results

An initial demonstration was completed to evaluate melting behavior and process parameters. The feed rate was started at 15 L/hour and then incrementally increased to as high as 50 L/hr. Pouring was performed in a batch mode versus continuous pouring. From 15 to 30 L/hr, the cold cap coverage was about 60% or less. Figure 1 gives a series of pictures of the cold cap at various feed rates. At 50 L/hr, the cold cap coverage was about 80% but a pressure drop in the off-gas system precluded extended operations at this feed rate.

Figure 1. Photographs of Cold Cap at Various Feed Rates

The baseline demonstration operating conditions were based on observations from the initial demonstration. The heat-up of the CCIM was performed the same as for the initial demonstration. The CCIM was fed at 40 L/hr for about 70.5 hours of steady operation. The feed rate was then increased to 50 L/hr for about 50 minutes without any issues. After this, the feed rate was increased to 60 L/hr for about 30 minutes. Some irregularities were noticed in the cold cap, but vent holes were still present in the cold cap. The test was terminated after 72 hours of feeding. As with the initial demonstration, pouring was performed in a batch mode for the baseline demonstration.

Table III summarizes the maximum feed rate, melt rate, waste throughput (WT), melt flux, and WT flux determined in the baseline demonstration at a waste loading of about 50 percent. The melt surface areas of the DWPF melter and the 550mm CCIM are 28.3 ft^2 (2.63m^2) and 2.557 ft^2 (0.2376 m^2), respectively. It was noted that the calculated melt flux of the CCIM at 1250^o C was 3 times higher than that of the DWPF melter design basis at 1150^o C despite having an order of magnitude smaller melt surface area.

Table III. Summary of Maximum Rates Determined in NETEC CCIM Baseline Demonstration

Melt Temp (ºC)	Max. Feed Rate gal/hr (l/hr)	Max. Melt Rate lb/hr (kg/hr)	Max. WT lb/hr (kg/hr)	Max. Melt Flux lb/hr/ft^2 (kg/hr/m^2)	Max. WT Flux lb/hr/ft^2 (kg/hr/m^2)
1250	13.2 (50)	62.4 (28.3)	31.3 (14.2)	24.4 (119.6)	12.2 (59.8)

The CCIM feed was doped with non-radioactive cesium (fed as $CsNO_3$) to target a 0.5 weight percent Cs_2O concentration in the glass to determine a rough estimate of cesium volatility in the CCIM. Analysis of the six glass pour samples taken indicated an estimated cesium volatility ranging from 34% to 70%. The DWPF design basis cesium carryover to the off-gas system is 10%. Therefore, testing to determine those process parameters that may be contributing to these higher than desired cesium carryover rates is needed.

LONG-TERM IMPACTS FROM RADIATION/CONTAMINATION WITHIN THE CHERNOBYL EXCLUSION ZONE – IRL AND SRNL

Scope of Work and Results

The following four tasks comprise the overall project:

- **Task 1** Characterization and Monitoring Methods.
- **Task 2** Understanding of the Processes and Modeling of Fate and Transport of Radionuclides through Environmental Pathways (e.g., soils, groundwater, surface waters, microbiota, plants and animals, etc.).
- **Task 3** Evaluation of Risk Assessment Methods.
- **Task 4** Evaluation and Demonstration of Cleanup Technologies for Radioactively-Contaminated Sites.

In turn, these four tasks consist of 18 subtasks, nine of which were completed, translated into English from Russian, and submitted to SRNL for review and approval. Below are the summaries of these nine reports.

<u>Subtask 1a. Monitoring of abandoned areas</u>: The ChEZ is an area in Ukraine that was contaminated by radionuclides as a result of the Chernobyl accident. The ChEZ has its own administrative system and its land is defined as radiation hazardous land. The ChEZ land is not allowed to be used for habitation or agricultural activities. This subtask report summarized radiation environmental monitoring, methodologies, studies, measurements, and development of maps in the Chernobyl Exclusion and Mandatory Evacuation Zones (Figure 2). It also described the hardware and software necessary to maintain the environmental monitoring database updated. In addition, the EcoCenter Enterprise currently possesses a comprehensive database that includes air, soil, and water monitoring data. Currently, this database is being updated with new hydrogeological information obtained by the Kiev EnergoProekt Institute from its newly installed monitoring wells.

Figure 2. IRL staff members performing a gamma-ray survey at the ChNPP Cooling Pond Dam.

Subtask 1c. Analysis of environmental monitoring methods used during and after decommissioning of Chernobyl nuclear power plant: After Ukraine became an independent nation, the focus of remediation and monitoring in and around the Chernobyl Nuclear Power Plant (ChNPP) changed due to various economic and ecological reasons. Instead of undertaking large, extensive, and expensive remediation projects, the current focus is on self-attenuation, which is called Monitored Natural Attenuation (MNA) in the West. Site characterization and long term monitoring are important aspects of MNA. This subtask report documented the environmental monitoring (radiological and chemical) performed and established in the ChNPP industrial zone during decommissioning of the ChNPP and the stabilization of the Shelter for the damaged reactor. A "current" snapshot status (from 1998 to 2003) of the concentrations of the usual radionuclides of interest (^{137}Cs, ^{90}Sr, ^{238,239,240}Pu, and ^{241}Am) in various media were presented. Exposure dose-rates recorded at 29 Automatic Radiation Monitoring System locations was also provided for this time period.

A summary of the quantity of various radiological and chemical effluents discharged to the air and surface water from ChNNP were then documented for the years 1999 to 2004. The most thorough database (from 1988 to 2001) was provided for the trending of ^{90}Sr and ^{137}Cs in the ChNPP Cooling Pond and in the groundwater near the Cooling Pond and Pripyat River. As would be expected, these datasets showed a steady decline in the water and groundwater concentrations. However, relative to U.S. standards, the contaminant concentrations remained high. For example, the mean concentration of ^{90}Sr in the Cooling Pond water and in the nearby groundwater was reported for the year 2001 to be approximately 3 Bq L^{-1}, or about 80 pCi L^{-1}. This is a factor of 10 higher than the U.S. Environmental Protection Agency drinking water standard of 8 pCi/L.

Subtask 1d. Analysis of environmental monitoring methods during cleanup of abandoned areas within the Chernobyl Exclusion Zone: The purpose of the radiation environmental monitoring associated with construction activities at ChNPP is to obtain valid and accurate information on contamination of the facilities under construction, areas of construction, buildings, structures, construction waste, construction materials and equipment, water supply systems, as well as information on radiation status of the completed facilities, buildings, and structures to be decommissioned. This report described the procedures and equipment used for radiation surveys and dosimetry work in the exclusion zone. The radiochemical techniques and instrumentation used for the analysis soil and water samples on a routine basis through out the ChEZ were also discussed in this report. A review of the instruments and procedures used to survey and monitor large areas, deep soil profiles and ground-water wells was also presented. In addition, the authors reviewed the radiological survey and monitoring procedures for planned, on-going and newly constructed structures. This included a radiological evaluation of construction materials, the physical site and personnel. The last report sections provided the administrative control limits for radiation and contamination of personnel and equipment in the ChEZ.

Subtask 2c. Assessment of groundwater contamination caused by the cooling pond at the ChNNP, and evaluation of radiological conditions during the decommissioning of the cooling pond: Using data from government agencies and internal Chernobyl Center reports, the subtask report discussed the geography, geology, hydrology and climatology of the area. The design of the cooling pond and its operation were described in detail. This subtask report provided data on the cooling pond's various water inputs and outputs through evaporation and seepage between 2000 and 2003. The cooling ponds water chemistry, radiological contamination, microclimates, and biological communities before and after the 1986 accident were described in the report. In 2001 the Ukrainian Academy of Science, Chernobyl NPP, and EcoCenter scientists conducted a field experiment to determine the cooling pond's water balance. The report also provided data taken from reports between 1981 and 2006 on the evolution of radioactive contamination of water and bottom sediments in ChNNP reservoirs and other area water bodies.

Subtask 2f. Analysis of experimental data and models describing radionuclide resuspension and aerosol transport caused by natural (e.g., wind) and anthropogenic (e.g., agricultural activities) factors: After airborne radioactive release from the destroyed Chernobyl reactor and subsequent radioactive fallout stopped in 1986, secondary wind transport of radionuclides became the major source of near-surface atmospheric layer contamination. Due to a vertical migration of radionuclides in soils causing reduction of their concentration in an upper dust forming layer, immobilization of the original radionuclide fallout by soil particles, dust suppression work, plowing and turfing of open soil areas accompanied by self-remediation of the natural complexes, airborne radioactive concentrations in the near surface air layer gradually decreased. The most significant decrease of airborne radioactive concentrations was observed during the first two years after the Chernobyl accident. Currently, the situation has been stabilized. Under natural weather conditions, the airborne radionuclide concentrations may vary by an order of magnitude during one year. However, during dust storms and wild fires, near-surface airborne radionuclide concentrations may increase by a factor of several hundreds. Agricultural activities in radioactively contaminated areas affect the soil and increase the release of airborne radioactive dust. Therefore, agricultural machine operators and agricultural workers are considered to be one of the highest risk groups with regard to radionuclide inhalation.

Subtask 2g. Evaluation of Effects of Microbiological Processes on the Speciation and Transport of Radionuclides in Soils Using Existing Data and Results of Additional Studies of Strains of Micromycetes with Positive Radiotropism: The speciation of the soil micromycetes in the ChNPP 10-km Exclusion Zone have been studied from 1986 until present. Six soil sampling stations were established in the spring of 1987. The heavily contaminated soil samples contained a prevailing number of melanin bearing micromycetes (up to 40%), which characterized the process as induced melanization of the soil mycobiota. The quantity of fungal mycelium in the contaminated soils of the ChNPP 10-km Exclusion Zone was determined by identifying the total lengths of light and dark colored fungal mycelium depending on their contamination, depth, and time of year. Since 1988, there has been a significant decrease in the amount of dark colored mycelium and a constant increase in the light colored. The mycelium biomass ranges from hundredths of a milligram to a few milligrams per one gram of soils, which means dozens and hundreds of kg of the fungal biomass for one hectare. During the 20 years after the accident, the number of identified species ranged from 80 to 112, with the most significant changes in the speciation occurring between 1995 and 1998. After the Chernobyl accident, scientists needed to study "hot" particles that represented fuel finely-dispersed particles of complex composition with a high specific activity. The purpose of one such study was to identify tropism associated with interactions of micromycetes with hot particles or low intensity γ-irradiation sources. The number of strains capable of positive radiotropism did not exceed 20% of those found in radioactive soils. The authors concluded that the micromycetes that grow directionally towards the irradiation source are likely to destroy hot particles.

Subtask 4c. Evaluation of the results of observations and modeling related to the effects of natural attenuation of radionuclides in grassland and at former agricultural lands: This report was a literature review on the processes of auto-remediation (self-remediation) of the components of the wild grassland and former agricultural cenoses in the ChNPP Exclusion Zone, including vertical migration of radionuclides, radionuclide immobilization in soils and other physical and chemical properties. This report also presented the available published data, as well as experimental data and calculations on the major processes that affect auto-remediation of the ground level systems and their components in the Chernobyl Exclusion Zone and ChNPP Mandatory Evacuation Zone. One of the most significant characteristics of the ChNPP related fallout, regarding subsequent environmental impact in the ecosystems, was associated with fallout of difficult to dissolve finely dispersed nuclear fuel particles with various degrees of physical and chemical transformation of their matrices. This report described physical and chemical forms of the radioactive fallout in detail, their transformations in soils and generation of radionuclide mobile forms, and dissolution of fuel particles in various soils under various chemical conditions. Long-term vertical migration of ChNPP associated radionuclides in typical soils of the wild grassland and former agricultural cenoses of the ChNPP Exclusion and Mandatory Evacuation Zone was evaluated.

Subtask 4a. Analytical nonradiochemical techniques to determine ^{90}Sr, ^{238,239,240}Pu, and ^{241}Am in soil and sediment samples: Well-known physical and chemical methods have been developed for radioecology studies. Therefore, methods to measure radionuclide concentrations in the environment are also well developed. However, these measurements often require long-term and expensive radiochemical procedures; especially, when dealing with popular radionuclides in radioecology such as strontium, uranium, and plutonium. Sometimes it is necessary to obtain measurements of the same sample hundreds or even thousands of times. The reasons for such a large number of measurements vary from monitoring laws to scientific tasks. The cost of these measurements can be unreasonable when compared to results obtained from theoretical methods. These methods for ^{90}Sr, ^{238,239,240}Pu, and ^{241}Am were described in this report.

Subtask 3a. Methods of Radiation Dose Assessment to Human and Non-Human Species: The interpretation of numerous biological effects caused by radiation demands adequate knowledge about dose burden received by certain biological systems. History and circumstances of the exposure are also important factors when estimating dose. Even in laboratory conditions with controlled exposures and a well-known radiation source, the estimation of absorbed dose in certain tissues and organs is a rather complicated task. In real situations when a number of radiation factors with different characteristics act on dynamically developed biological systems, the estimation becomes extremely complicated and unlikely solvable without obligatory simplifications and conditional admissions. In the former Soviet Union and countries formed after the former Soviet Union, the problem of dose assessment was always very important, and researchers elaborated several methods and techniques, which in a whole are close to methods known in the western world. This report included brief reviews of some methods and approaches that were applied in Russia, Belarus and Ukraine during the last 20 years (post-Chernobyl period) to estimate absorbed dose in humans and wild biota (Figure 3).

Figure 3. IRL staff member measuring Cs-137 and Sr-90 concentrations in birds in a mobile laboratory

Path Forward

The remaining subtask reports for FY2009 include the following:

- Radioecological state of abandoned areas during and after remediation
- Monitoring methods during ChNPP decommissioning and Shelter's stabilization.
- Modeling of groundwater contamination in the ChEZ
- Evaluation of a program for drainage of ChNPP's cooling pond after its decommission
- Modeling of radionuclides migration in soils. Formation of exposure doses to population
- Long-term observation of radionuclides migration in the ecological chain links "soil–animals"
- Dose-response in environmental endpoints
- Evaluation of potential application of the project results at DOE sites

It is planned that a compilation book will be published that will include executive summaries of all subtask reports.

FUTURE ACTIVITIES

Cold Crucible Induction Melter Modeling and Control

Idaho National Laboratory (INL) and St. Petersburg Electrotechnical University (ETU-LETI) have collaborated in the past on investigation of the Cold Crucible Induction Melter (CCIM) technology. These efforts have been focused in three areas: modeling, development and testing of an innovative glass draining technology, and automated control methodologies and systems. A model has been developed and validated that predicts temperature distribution, convection features, and energy distribution characteristics for CCIM systems with one or two induction energy sources. The model accounts for temperature dependence of key properties in the melt, including electrical resistivity, thermal conductivity, specific heat, and density, which directly control the melt status. This model is a unique analytical tool that can be used to conduct a myriad of investigations, such as sensitivity analyses for factors of interest (i.e. geometry, configuration, scaling effects, material properties, etc.), to better understand the operational characteristics and optimize system designs. The drain technology is based on the same principles as a CCIM, but on a much smaller scale (i.e. 2.5 cm versus 30 cm) that is operating simultaneously with the primary induction energy source. These size and interaction factors introduce design challenges that would have required much more time and cost to solve without the modeling capabilities. The drain system has been demonstrated to successfully and repeatedly open and close due solely to energy deposition, incorporating no moving components. The drain concept has been validated and could be readily incorporated into virtually any melter system, with additional development and optimization. Significant advances in establishing a reliable automated feedback control system have also been realized. Novel sensors have been developed that allow for direct and indirect measurement of key electrical parameters (e.g. power factor shift) that can be correlated to the status of the melt volume (Figure 4). Specifically, the bulk temperature and corresponding electrical resistivity can be determined, which drive the ability of the induction field to efficiently couple with the melt.

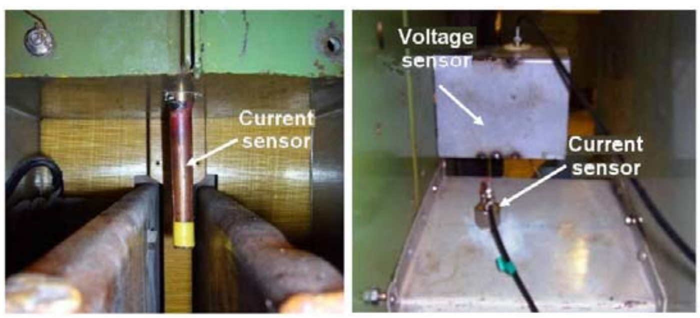

Figure 4. Current and voltage sensors installed on CCIM.

The new work will be focused in three areas:

- <u>Modeling and Experimental Validation</u>: Investigations will be made to better understand and quantify the differences between the model and experimental results, with specific focus on the temperature distribution, which is most readily measured yet an outstanding representation of the validity of the model. Sensitivity analyses will be conducted on key model parameters, including electrical resistivity, thermal conductivity, specific heat, density, mesh size, induction cage size, and time step size, to quantify the impacts and optimize as appropriate.
- <u>Drain Device Development</u>: Efforts will be made to refine the drain configuration and, using the model and experimental results, identify key controlling parameters and correlate them to operational applications. Areas of investigation will include the geometry and/or necessity of a minimum bog area to support complete evacuation of the melt while maintaining coupling capability with the induction field.
- <u>Automated Control</u>: Work will be conducted to refine the calorimetry measurement system and data to better correlate with the sensor data, with the focus on developing more quantitative

relationships between the sensor readings and melter state. Another key area is to better understand the response time or lag associated with a change in the power setting or frequency and re-establishing steady state.

Designing and Testing Improved "Reducing" Hydraulic Reagents for Application to Savannah River Saltstone Waste form

Replacement materials for the slag cement components in SRS Saltstone formulations are being considered. Slag cement is a ground silicate glass with a composition that results in both hydraulic reactions in the presence of water and alkalis. The drivers for the request to identify alternative materials for slag cement include:

- Improving cured property performance including chemical reducing potential which is responsible for chemical stabilization of contaminants such as pertechnate and chromate
- Improving processing (slurry properties and early curing properties such as heat of hydration)
- Increasing waste loading.

A task will be conducted by the SIA Radon Institute to develop alternate slag compositions based on previous glass chemistry experience. Compositional enhancements will be identified and evaluated for increasing the chemical reducing potential of the waste form by various mechanisms including increasing the amount of sulfur dissolved in the silicate glass structure to increase the reduction potential of the glass. When a successful glass composition is developed, bulk quantities of the synthetic slag will be produced for testing in Saltstone compositions.

Technical Exchanges in Accordance with DOE-EM and NDA Statement of Intent

A Statement of Intent was recently signed between DOE-EM and the U. K. Nuclear Decommissioning Authority (NDA) to work cooperatively on areas of mutual interest. Under this umbrella, information and technical exchanges have been identified as near-term actions to help meet the objectives of the Statement of Intent.

Technical interactions have commenced between the U.K.'s National Nuclear Laboratory and Sellafield Sites Ltd. and the U.S.'s SRNL and DOE-EM Office of Engineering and Technology in the area of high level waste vitrification. A series of videoconferences have been held where information has been shared on research being conducted in each country. This information is being collectively reviewed to identify common areas of interest. Future goals include identifying areas for collaborate research, technology sharing and personnel exchange.

The University of Manchester (U.K.) has established the Materials Performance Centre (MPC) NDA to provide an interdisciplinary center for training and research in nuclear materials science and engineering. Research within the MPC is addressing all aspects of the nuclear lifecycle through five key technical themes: Corrosion and Environmentally-Assisted Cracking; Advanced Fracture Mechanics; Structural Integrity; Nuclear Graphite; Fuel Cladding Materials and Predictive Modeling. The SRNL and other DOE National Laboratories are conducting related research and development to address materials challenges associated with environmental management and cleanup of DOE sites. Partnership between the MPC, SRNL and other DOE National Laboratories will help leverage complementary research to provide materials performance research fundamental to the nuclear industry in cleanup, decommissioning, plant operation and life extension consistent with the DOE-EM mission. Dialog will be initiated in FY09 between the U.K.'s NDA and MPC and the U.S.'s DOE-EM Office of Engineering and Technology and SRNL.

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