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LOW-LEVEL RADIOACTIVE WASTE VOLUME REDUCTION IN RUSSIA: PROCESSING OF SOLID AND LIQUID WASTE FROM SUBMARINE DISMANTLEMENT

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ABSTRACT

This paper describes the radioactive waste management activities associated with a U.S. Department of Defense (DoD) project to dismantle Russian nuclear submarines in northern and eastern regions of the Russian Federation. This effort, one of several on-going Cooperative Threat Reduction (CTR) projects sponsored by the Defense Threat Reduction Agency (DTRA), deals with the transportation, processing, packaging, and storage of solid and liquid low-activity waste at the Zvezdochka shipyard in Severodvinsk and the Zvezda shipyard in Bolshoi Kamen. Approximately 3000 m^3 of liquid radioactive waste (LRW) and 200 m^3 of solid radioactive waste (SRW) are processed at each site annually. A description of the technology used to achieve these volume reduction goals and the current state of this project are presented.

Background

In August 1998, Lockheed Martin Energy Technologies (LMET) was awarded a contract by the U.S. Defense Threat Reduction Agency to design, develop, fabricate, test, and deploy a turn-key low-level radioactive waste (LLRW) volume reduction system at two strategic submarine dismantlement facilities in the Russian Federation – the Zvezdochka Shipyard in Severodvinsk and the Zvezda Shipyard in Bolshoi Kamen. In addition, the project includes constructing a building capable of storing 1500 m^3 of processed waste at the Zvezda Shipyard as well as renovating the site infrastructure and an existing building at each shipyard. This CTR project assists the Russian Federation in the volume reduction of LLRW generated from the dismantlement of strategic submarines under the Strategic Arms Reduction Treaties (START).

The Russian firm Association ASPECT and its design agent VNIPIET are the main subcontractors to LMET responsible for the liquid/laundry LLRW subsystem. The French engineering firm SGN is LMET's main subcontractor responsible for the SRW subsystem. The Anglo-Norwegian company Kvaerner Process is the main subcontractor to LMET responsible for construction activities.

Waste Characteristics

The project implements technologies to volume reduce 1) 4000 m^3 per year of liquid/laundry LLRW and 200 m^3 per year of SRW at the Zvezdochka Shipyard to less than 100 m^3 per year and 2) 2500 m^3 per year of laundry LLRW and 200 m^3 per year of SRW at the Zvezda Shipyard to less than 50 m^3 per year.

Four types of liquid/laundry solutions will be cleaned: Primary Loop Coolant, Biological Shielding Water, a mixture of the aforementioned solutions (which includes organic-based decontamination solutions), and Radiological Laundry Wash/Rinse Water. Table 1 lists the chemical and radiological constituents of these solutions.

Three types of SRW will be processed: Combustible Waste (e.g., rags, protective clothing), Plastic-like Material (e.g., hoses, cable), and Metal (e.g., metal scrap). Table 2 lists the average annual amount and activity of these materials to be processed.

Technology Solutions

The liquid/laundry LLRW processing technologies that are being used are largely Russian in origin and include:

- sorption pre-purification with selective inorganic sorbents (Russian),
- microfiltration and reverse-osmosis purification to remove radionuclides and chemical impurities (Russian),
- two-stage concentration of brines to obtain dry salts using a rotary concentrator and drum heaters (Russian and U.S.),
- containment of spent sorbents, dry salts, and sludges in special protective containers, including 300-year design life high-integrity containers (HIC) and specially-lined 85-gallon drums (U.S.).

Such an approach has allowed us to reject traditional cementing processes that are a weak point in other Russian Federation waste management projects.

Figure 1 illustrates the simplified flow sheet for the Biological Shielding Water processing subsystem. Contaminated influent is first pumped from an external tank to a 6-m^3 holding tank. The influent is then pumped through a screen filter to remove particulate matter and other large impurities. The solution is next sent through a series of columns packed with sorbents engineered to have an affinity for Cs-137 and Sr-90. The solution is then sent to a reactor where $BaCl_2$ is added to produce and settle out $BaSO_4$. Excess barium ions are converted to $BaSO_4$ through the addition of Na_2SO_4. After intermediate tankage, the solution is pumped through a series of microfilters for final polishing prior to sampling and release. $BaSO_4$ salt sludge discharged from the precipitation reactor is collected in 55-gallon drums and dried using specially adapted drum heaters.

Table 1. Constituents of Liquid and Laundry LLRW Solutions

Primary Loop Coolant (200 m^3 per year)			
RADIONUCLIDE		CHEMICAL (pH = 9 – 10.6)	
Constituents	Concentration (Ci/l)	Constituents	Concentration (mg/l)
Volumetric Activity	$3 \times 10^{-6} – 3 \times 10^{-5}$	Ammonia	100 – 600
Transuranic Activity	$5 \times 10^{-10} – 1 \times 10^{-8}$	Hydrazine	50 – 600
^{14}C	$2 \times 10^{-6} – 2 \times 10^{-5}$	Salt Content	5 – 10
^{55}Fe	$7 \times 10^{-7} – 3 \times 10^{-5}$	Solid Residue	1 – 20
^{63}Ni	$3 \times 10^{-7} – 2 \times 10^{-6}$	Oxidizable Material	5 – 10
^{60}Co	$1 \times 10^{-7} – 1 \times 10^{-6}$	Chlorides	0.1 – 0.2
^{90}Sr	$5 \times 10^{-7} – 5 \times 10^{-6}$	Iron	0.5 – 1
^{137}Cs	$2 \times 10^{-6} – 2 \times 10^{-5}$	Phosphate Ions	100 – 250
^{3}H	$1 \times 10^{-5} – 5 \times 10^{-3}$		
Other	$3 \times 10^{-7} – 3 \times 10^{-6}$		
Bioprotection Water (700 m^3 per year)			
RADIONUCLIDE		CHEMICAL (salt content = 20 m/l)	
Constituents	Concentration (Ci/l)	Constituents	Concentration (g/l)
Volumetric Activity	1×10^{-6}	Cl^-	11
^{35}S	1×10^{-6}	$SO_4^=$	1.5
^{45}Ca	1×10^{-8}	$HCO_3^=$	0.8
^{54}Mn	6×10^{-10}	Br^-	0.4
^{55}Fe	2×10^{-8}	F^-	0.0006
^{60}Co	1×10^{-9}	$H_3BO_3^-$, HPO_4^-	0.014
^{90}Sr	1×10^{-9}	Na^+	6.12
^{137}Cs	1×10^{-8}	Mg^{++}/Ca^{++}	0.98
		K^+	0.22
		Sr^{++}	0.006
Laundry Water (2500 m^3 per year)			
RADIONUCLIDE		CHEMICAL (pH = 10.4)	
Constituents	Concentration (Ci/l)	Constituents	Concentration (mg/l)
Volumetric Activity ($^{90}Sr/^{90}Y$: 5%; ^{60}Co: 30%; ^{137}Cs: 65%)	$2 \times 10^{-9} – 2 \times 10^{-8}$	Suspended Matter	2100
		BOD	760
		Phosphates	36
		Dry Residue	3800
		Ammonium Nitrate	31
		Surfactants	160
		Chlorides	208
		Petroleum Products	600
Decontamination Solutions (50 m^3 per year)			
RADIONUCLIDE		CHEMICAL	
Constituents	Concentration (Ci/l)	Constituents	Concentration (mg/l)
Volumetric Activity (^{90}Sr: 10%; ^{60}Co: 5%; ^{137}Cs: 50%; ^{55}Fe: 20%; Other: 15%)	$1 \times 10^{-7} – 1 \times 10^{-5}$	H_2CrO_4, H_3PO_4, HNO_3, H_2SO_4, CrO_3, $CH_3C(OH)(PO_3H_2)_2$, $C_{10}H_{14}N_2Na_2O_5$, Surfactants	Not reported

Table 2. Characteristics of Solid Radioactive Waste

Type of Waste	Specific Activity (Ci/m^3)	Surface Contamination (β-particles/cm^2-min)	Annual Amount (m^3/year)
Combustible (rags, protective clothing, wood, etc.)	6.7×10^{-3}	600	60
Plastic, Polyethylene, and Rubber (insulation, cables)	2.0×10^{-3}	100-1000	80
Metal (parts and pieces of equipment)	1.3×10^{-4}	100-500	60

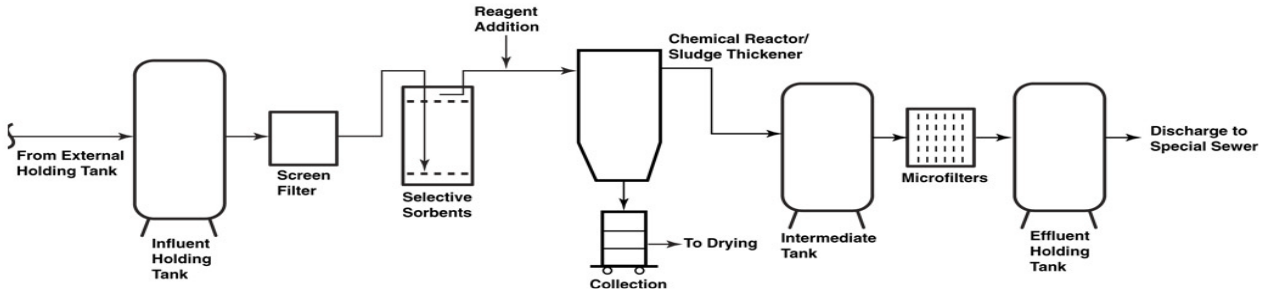

Figure 1. Biological Shielding Water Subsystem

Figure 2 illustrates the simplified, combined flow sheet for the Primary Loop Coolant and the Mixed Solution processing subsystems. Contaminated influent is first pumped through screen filters to remove gross impurities and then sent through a series of sorbent column to remove Cs-137, Sr-90, and Co-60. Multi-stage reverse osmosis is next used to remove inorganic salts. Reject from the reverse osmosis units is concentrated through thermal or chemical means and collected in 55-gallon drums for final drying via drum heaters. Permeate from the reverse osmosis units undergoes ozonation and carbon filtration to extract nitrogen-containing and organic impurities. Residual radionuclides are removed via another series of selective sorbents. Final polishing is accomplished using ion-exchange columns.

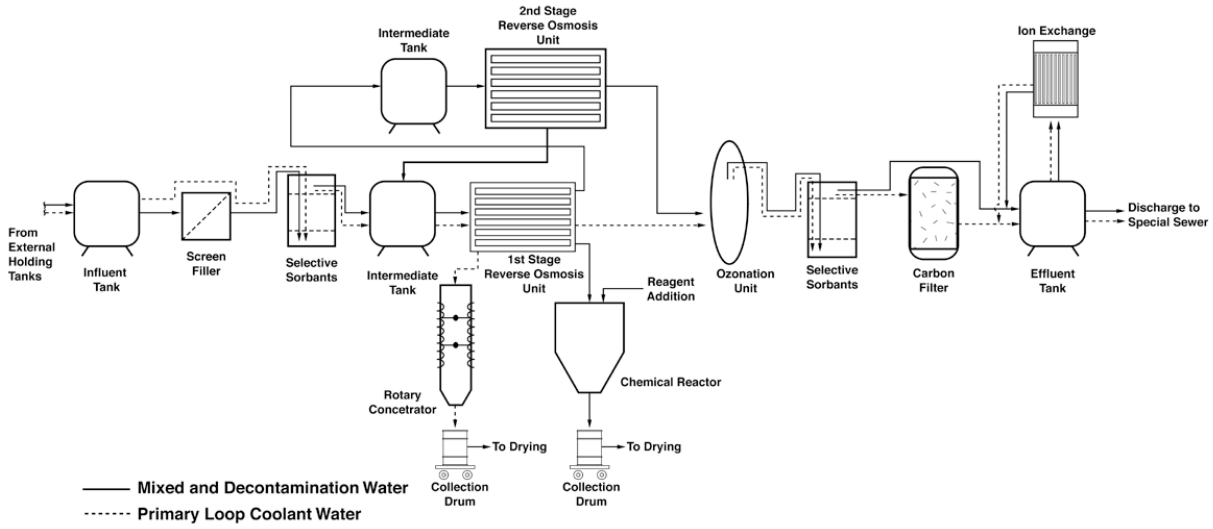

Figure 2. Primary Loop Coolant and Mixed Solution Subsystems

Figure 3 illustrates the simplified flow sheet for the Radioactive Laundry Water subsystem. Contaminated influent is first pumped from an external tank to two 6-m^3 holding tanks. The influent is then pumped through a screen filter to remove lint, particulate matter and other large impurities. Next the solution is discharged into a settling reactor where insoluble oil products are separated and phosphate salts, mildly radioactive surfactants, and hardening salts are precipitated through the addition of coagulants and flocculents. Insoluble oil products are skimmed from the settler and collected for subsequent binder addition and hardening. Inorganic precipitants in the settler are sent to a thickener, collected in 55-gallon drums, and dried using drum heaters.

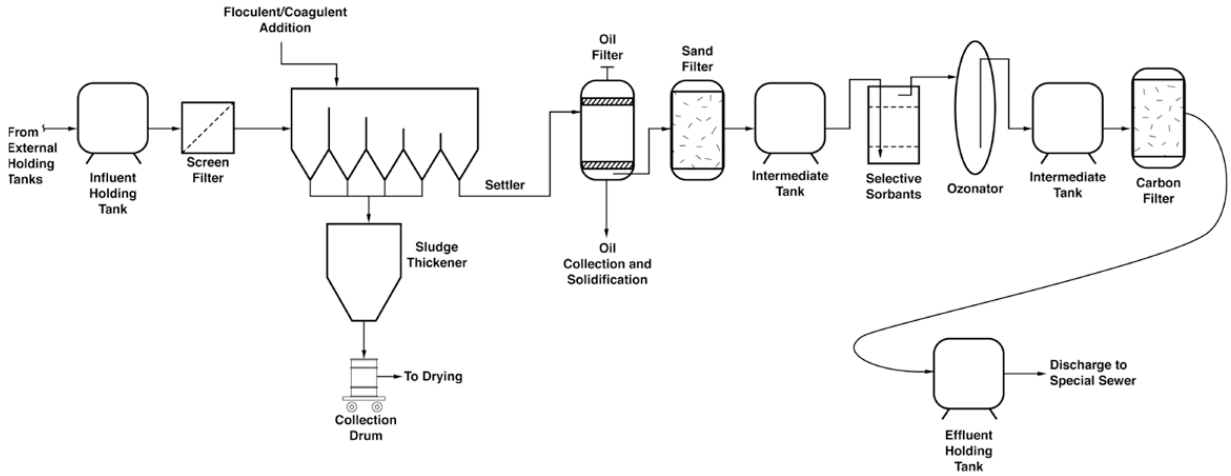

Figure 3. Laundry Water Subsystem

Residual oil and inorganic impurities are subsequently removed via coalescent (i.e., polyurethane foam) and sand filtration unit operations. Emulsified petroleum products are later removed via ozonation and carbon filtration. Radioactive impurities are removed from the solution by a series of columns packed with sorbents engineered to have an affinity for Cs-137 and Sr-90. Final polishing by ion-exchange columns (not shown) is provided to remove persistent mineral salts.

The SRW processing technologies are similar to technologies widely used in LLRW management applications throughout the U.S. and Europe and include the following:

- HEPA-filtered containment boxes with glove ports to sort and size various types of waste (plastics, metal components, clothing, wood),
- portable, hand-held electro-decontamination units to decontaminate metals, and
- 60 ton low-force compactors for direct volume reduction.

Much of this technology is new to Russian radioactive waste regulatory authorities and has required close scrutiny and test demonstrations.

Figure 4 illustrates the sequence of operations associated with the SRW processing subsystem. Containerized SRW ("trash") is delivered to the facility via forklift. The containers are mounted to an automated tiling mechanism than empties the contents into a filtered, glove-ported sorting box. The SRW is sized (if necessary) and sorted according to its processing characteristics (e.g., compressible, non-compressible) and placed into 55-gallon drums. Drums of compressible waste are sent to a low-force compactor for volume reduction. After monitoring, the drums are transferred to storage.

Large metal objects (e.g., pumps and pipes) are delivered to the facility via forklift where they first undergo size reduction by disassembly or cutting. These parts then undergo electro-decontamination to remove "hot spots." Smaller parts are then placed inside 55-gallon drums that are monitored and sent to storage. Larger parts that cannot be containerized are monitored, wrapped, secured to pallets, and sent to storage.

Schedule and Milestones

Due to the international nature of the technology used, special attention had to be paid to the Russian nuclear and ecological licensing and certification process. All design documentation was prepared in accordance with normative requirements of the Russian Federation and has gone through all stages of coordination with all relevant federal agencies, including Gosatomnadzor (the Russian national nuclear safety authority) and Goskomekologiya (the Russian national environmental authority).

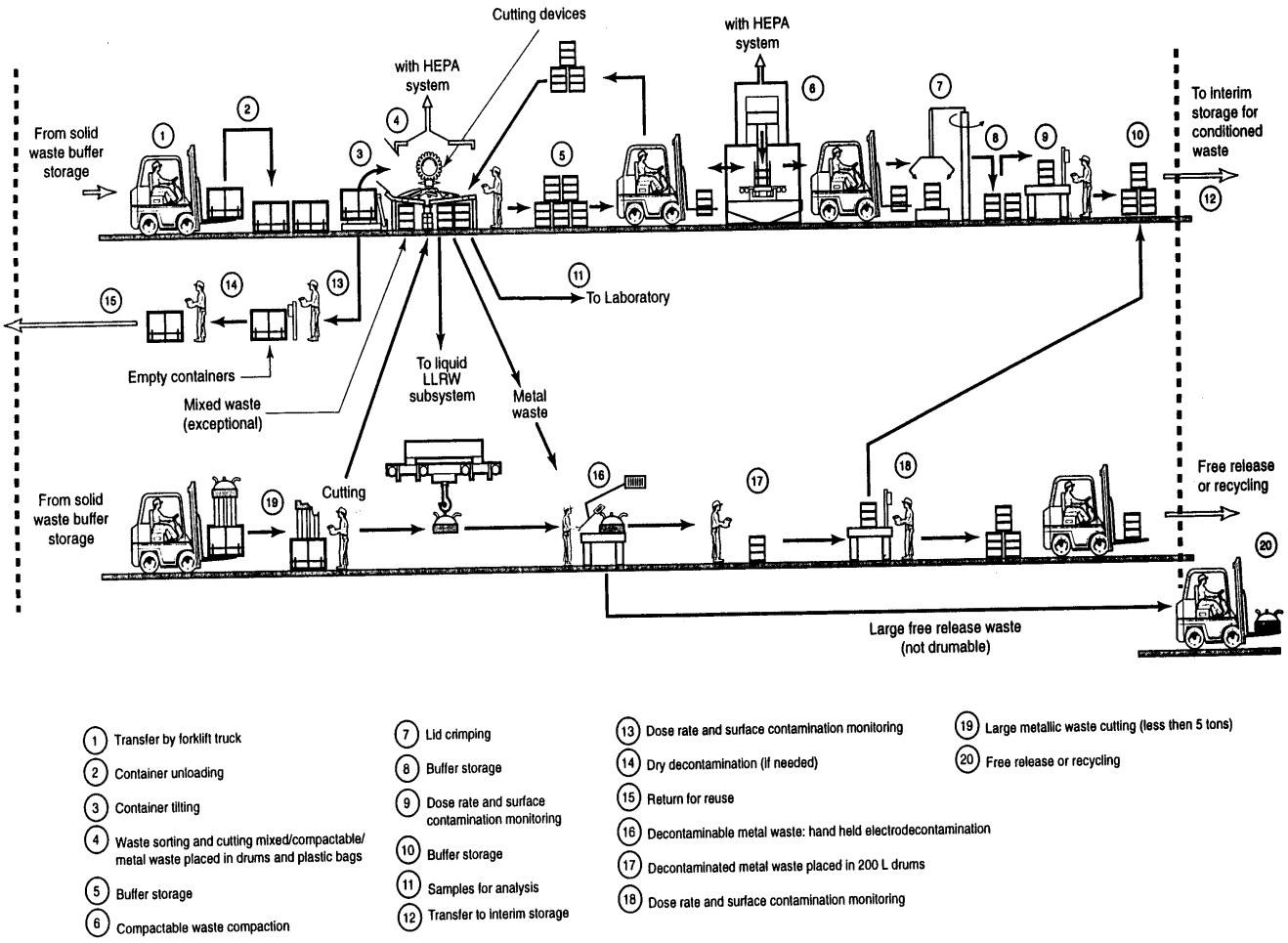

Figure 4. Solid Radioactive Waste Subsystem

Engineering and environmental surveys and design activities began in September 1998. The first design submittal to the Russian Federation (called the "Declaration of Intentions and Approvals, Technical Description of the System" – roughly equivalent to a conceptual design in the U.S.) was delivered and approved in October 1998. These documents included a request for permission for preparatory construction by local authorities and Goskomekologiya.

The next stage of the design (called in Russia the "Phase I or Working Design") – roughly equivalent in the U.S. to a preliminary design) was delivered to Russian authorities in February 1999. The Working Design is the principal vehicle for eliciting and securing all regulatory approvals for nuclear construction projects in Russia. (For example, the start date for construction activities at each site – June 1999 – depended on the Working Design reaching a specific level of maturity.) After being approved at regional and local levels in July, the Working Design was approved by Gosatomnadzor and the Russian Ministry of Economics (the Russian Cabinet-level authority responsible for administering U.S. aid projects) on October 1, 1999.

A Russian Final Design package (essentially identical to a Final Design in the U.S.), was developed in parallel with the approval process for the Working Design and completed in August. Designers met with regulators constantly to apprise them of the details in the Final Design, as well as to answer many questions and comments. The Final Design did not require its own formal approval process, since approval of the design at this stage is based upon successful system qualification tests.

At present (February 2000), the renovation of the existing structures and the physical infrastructure of each site are essentially complete. Construction activities for the new storage facility at Zvezda are also nearing completion. Installation of process equipment began in December 1999 and is 80-95% complete. Functional tests are ongoing and is scheduled to be conducted in March. Final system qualification (i.e., cold and hot) testing is scheduled to take place in April. Project completion is scheduled for April 30, 2000.

Conclusions and Lessons Learned

This paper describes the technology being used to address radioactive waste management issues at two Russian submarine bases currently conducting dismantlement activities. The technology solutions chosen are predominantly Russian in origin, except for SRW processing and container technology, which is mostly of Western origin. This "turn-key" project (survey, design, licensing, permitting procurement, construction, installation, and testing) has taken place in the timeframe of August 1998 to April 2000. Teams spanning 17 time zones have worked to implement one of the first and largest international radioactive waste management projects in Russia. At the present time, equipment installation and functional testing are being conducted.

Numerous lessons have been learned by the project team from the combination of challenging technical requirements, an aggressive schedule, and multi-national partners. The following is a partial list of the most important lessons learned in the area of conducting technical projects in Russia:

1. **Russian facility managers have considerable veto power** – the Director and Chief Engineer at each Russian installation have legal obligations to ensure that Russian norms and standards are followed. Therefore, these individuals must be kept well informed of all technical solutions being proposed and implemented. Surprises are normally dealt with negatively. Critical technologies that have not received wide use in Russia should be demonstrated to the facility managers.

2. **Purchasing equipment is Russia is challenging** – there is no such thing as a Thomas Register in Russia. Equipment must be purchased from certain "certified enterprises" that have long delivery times and high prepayment requirements. Ordering Russian equipment will require much more effort than Westerners are accustomed to. Furthermore, last-minute items are difficult (if not impossible) to obtain quickly. The idea of placing a call to a local industrial supplier and having an item rushed to the job site is often not practical at closed cities. Procurement plans must be carefully scrutinized to assure that all necessary and contingent equipment is sent to and arrives at the work site well before assembly begins.

3. **Start the licensing and permitting process immediately and never stop pushing** – the Russian licensing process is as complicated and often more mystifying (to Westerns) than the licensing process in the United States. It is crucial that individuals fully knowledgeable in the Russian licensing process actively and fully support the project and to stay in almost-constant contact with Russian regulators. It is also important that all non-Russian equipment have a well-established and well-documented quality and safety pedigree. Each key piece of non-Russian equipment should have its own "dossier" that includes ISO-9000 compliance (or equivalence), drawings, operating instructions, testing procedures and results, and documentation of similar use inside or outside Russia.

4. **Start demolition/construction activities as soon as possible** – establishing and maintaining construction momentum is extremely difficult from 17 time zones away. It is imperative to mobilize to each site as soon as possible, establish a construction trailer as close to the site as possible, and begin discussion with the site Director/Chief engineer and local contractors as soon as possible. Under the best circumstances, things move slowly in these remote regions. There will be hundred of local complications and details to work out before the "real work" begins. If these realities of doing work in Russia are not appreciated and respected, significant construction delays can be expected.

5. **US-Russian agreements need special attention at the local supplier level** – National agreements, such as the exclusion of the Russian national value-added tax (VAT) for U.S.-Russian aid programs, are not automatically complied with by Russian suppliers. Considerable effort and the development of an auditable trail of federally endorsed documents were required to assure Russian suppliers that such actions were legal and that the numerous lower-tier suppliers were also not entitled to VAT. Schedule delays were experienced because Russian suppliers would not supply equipment until the legal, tax, and equity issues associated with these seemingly straightforward issues were resolved.