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Pacific Northwest National Laboratory

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U.S. Department of Energy

Needs Assessment for Remote Systems Technology at the Chornobyl Unit 4 Shelter

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Prepared for the U.S. Department of Energy
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Summary

The accident at Chornobyl Unit 4 on April 26, 1986, resulted in a series of unprecedented scientific and technical challenges. The reactor building was damaged extensively. The reactor core was destroyed completely. Following the accident, immediate action was needed to seal off the gaping crater created by the accident, which was a continuing source of airborne contamination. Under extreme conditions, a structure called the "Shelter" was built over the remains of the reactor building. The Shelter, which was quickly completed in November 1986, was meant to provide immediate but temporary containment. Now, 11 years later, there are significant concerns about its structural integrity and projected life expectancy.

The United States and other participating G-7 countries (Britain, Canada, France, Germany, Italy, and Japan) are supporting nuclear safety upgrade efforts in Eastern Europe with a primary focus on placing the Chornobyl Nuclear Power Plant (ChNPP) Unit 4 Shelter in a stable and environmentally acceptable condition. Application of remote systems technologies will play an important part in achieving the goals of this program. The G-7 nations have agreed to support these efforts, including the identification and development of remote system technologies for fuel removal. However at this time they have taken a firm stance against funding actual fuel removal activities.

The U.S. Department of Energy (DOE) Office of Nuclear Energy, Science and Technology requested that a needs assessment be performed to evaluate the requirements for applying remote systems, including robotics, at the Shelter. This document is intended to be used to identify remote systems needs and requirements at the Shelter and to provide general information on the conditions in the Shelter that could impact the use of remote systems. This document is intended as a source of information to assist those who will be implementing the Shelter Implementation Plan tasks. The document provides background information and general guidance on the application of remote systems. This document is not intended to define how to meet the identified needs. The requirements and specifications for systems will be defined in followon work.

In 1996, the European Commission completed a study detailing concepts and cost analyses of five scenarios for the decontamination and decommissioning of the Chornobyl Shelter. Subsequently, a team of technical experts under G-7 sponsorship developed an integrated Shelter Implementation Plan. This plan defines 22 tasks to achieve five broad objectives:

- Task Group 1: reduction of accidental collapse potential
- Task Group 2: reduction of accidental collapse consequences
- Task Group 3: improved nuclear safety
- Task Group 4: improved worker and environmental safety

- Task Group 5: long-term strategy and study for conversion to an environmentally safe site.

The work outlined in the Shelter Implementation Plan will be organized into specific projects that will be funded through contributions of the G-7 nations (pledges), which will be managed through the European Bank for Reconstruction and Development (EBRD). The G-7 nations voted to provide $300M funding to the EBRD to support the Chornobyl Shelter works at the June 1997 Summit meeting in Denver, Colorado (*Energy Daily* 1997). The EBRD will act as the contracting agency to disperse the funds through a project tendering process. Currently, it appears that plans are to address remote systems needs as part of the individual projects that are commissioned through the EBRD. There is no current plan for an independent remote systems technology program sponsored by the U.S. DOE under the INSP.

Analysis of this plan and information obtained from onsite interviews with subject-matter experts in Ukraine indicates the following areas of need related to remote systems:

- Structural Investigations: Conduct inspections and install sensors to monitor and determine the integrity of the building support structures.

- Structural Stabilization: Install shoring or new structural supports, to reduce collapse potential.

- Water Management: Determine the amount and pathways of water entering and moving through the Shelter, and minimize or control water flow.

- Dust Management: Determine the amount and pathways for movement of airborne contamination in the Shelter, as well as support measures to reduce dust levels.

- Radiation Safety: Install and monitor radiation and criticality sensor systems.

- Fuel Investigations: Determine the amount, configuration, and physical properties of the fuel and fuel-containing materials in the Shelter.

Several different types of generic remote systems could be used to meet these needs. These systems include

- inspection and diagnostic systems for sensor deployment

- debris management systems to clear access and work areas

- material handling systems for materiel delivery and removal

- deconstruction systems to demolish and remove equipment and building structures

- construction systems to reinforce structures and to install new auxiliary structures.

Table S.1 provides a consolidated and comprehensive view of the types of remote systems identified in this study through the Shelter Implementation Plan and in interviews with Shelter Operations staff. This table summarizes potential remote systems needed across all of the Shelter Implementation Plan tasks. It also shows where the various classes of remote machines are likely to be needed. Table S.1 is acomposite of Tables 4.2, 4.3 and 4.4 in this report. Structural stabilization task and the safe confinement tasks will involve all three classes of remote systems. Only Classes I and II will be needed for the other tasks.

System Classifications

Class I remote systems (payload = 10 to 100 kg): small systems that are agile and light, used primarily for diagnostic, sampling, inspection, and sensor placement missions within the Shelter.

Class II remote systems (payload = 100 to 1,000 kg): medium-sized systems that are able to perform material handling and manipulation associated with work tasks like debris and shielding handling.

Class III remote systems (payload = 1,000+ kg): major machines required to perform full-scale building structure construction and deconstruction activities and large-volume debris removal operations within the Shelter.

Recommended Actions

- Use a step-wise approach to implement remote systems starting with simple and robust technologies applied in easily accessible areas where operations can be tested.
- Develop detailed system functional and technical requirements to reduce costs for system development and acquisition. Consider sponsoring a technical working group to define fundamental remote systems requirements necessary to perform the remote tasks identified in this document.
- Thoroughly investigate available remote technology, for example, alternatives to vehicles for accessing hard-to-reach areas.
- Initiate early remote systems projects focusing on high-priority needs, like diagnostic systems for structural assessments and environmental characterizations.
- Establish integrated project management for coordination of remote systems initiatives. Consider creating a supporting consulting board of independent experts to assist in implementation of projects requiring remote systems.
- Establish a remote systems technology facility for equipment testing, operator training, and operations support.
- Plan for supporting infrastructure, maintenance facilities, and staff training.

Conclusions

There is no question that remote technology can be deployed in a reliable manner that reduces worker radiation exposure in a wide range of tasks. This assessment confirms the need for remote systems technologies, including robotics, to support day-to-day operations in the Shelter and implementation of both short- and long-term stabilization and remediation tasks defined in the Shelter Implementation Plan. Remote systems can play a role in significantly reducing the dose uptake to personnel working in the Shelter and provide the capability to perform work not previously possible due to the hazard levels.

The cost of such systems will no doubt be very high in the perspective of the Shelter operating staff. It is unlikely that they would consider such systems cost-effective in the absence of pressure to reduce dose uptake. The radiation exposure standards used at the Shelter will have great bearing on which applications are considered for implementation. The funding levels provided to support Shelter Implementation Plan projects will affect priorities and decisions on remote technology applications. A centralized approach to the management and deployment of remote technology should be carefully considered as a way to address remote system acquisition and deployment in a cost-effective manner.

The successful implementation of remote technologies will depend on careful planning and development of definitive functional requirements and design criteria that accurately reflect the nature of the work to be performed and the challenges of the operational environment. It is recommended that the application of robotics and remote systems be approached in a stepwise fashion, starting with simple and robust technologies applied in readily accessible areas where operations can be tested. Experience thus gained in operating systems and lessons learned on system performance can be applied in expanding applications to more sophisticated equipment and challenging areas. Testing of systems in simulated conditions and training for personnel to operate the equipment in the Shelter are important factors to achieve successful remote operations. Improvement of testing and training facilities and infrastructure enhancements at the Shelter will be needed to support deployment of remote systems technologies.

Table S.1. Summary of Remote System Needs at Chornobyl Iden

Shelter Implementation Plan Tasks	Remote Operation Requirements from SIP Tasl								
Immediate to Mid-Term Tasks	Debris Clearing	Ingress/Egress Route Preparation	Shielding Installation	Utility Service Installation	Radiation Surveys	Shielding/Decontamination	Structural Inspection	Materials Transport	Structural Stabilization Installation
Structural Stabilization Task Group (Tasks 1-8)									
1. Stabilization & Shielding Design Integration & Mobilization	•	•	•	•	•	•			
2. Western Section	•	•	•	•	•		•		
3. Mammouth Beam & Southern Section	•	•	•	•	•	•			
4. Eastern & Northern Sections	•	•	•	•				•	•
5. Roof, Roof Supports & Covering					•				
6. Structural Investigation & Monitoring						•	•	•	•
7. Geotechnical Investigation	Remote Systems Not Applicable								
8. Seismic Characterization & Monitoring	Remote Systems Not Applicable								
Collapse Accident Consequence Mitigation Group (Tasks9-11)									
9. Emergency Preparedness									
10. Dust Management									
11. Emergency Dust Suppression									
Improve Nuclear Safety Task Group (Tasks 12-14)									
12. Criticality Control & Nuclear Safety		•			•				
13. Contained Water Management					•				
14. FCM Characterization		•			•				
Worker Safety Task Group (Tasks 15-18)									
15. Radiological Protection Program	Remote Systems Not Applicable								
16. Industrial Safety Program	Remote Systems Not Applicable								
17. Integrated Monitoring System	Remote Systems Not Applicable								
18. Integrated Database	Remote Systems Not Applicable								

Shelter Implementation Plan Tasks	Remote Operation Requirements from SIP Task								
Long-Term Tasks	Ingress/egress to FCM Locations	FCM Mapping & Analysis	FCM Size Reduction, Special Tooling	FCM and Waste Sorting, Handling & Packaging	Criticality & Dust Monitoring	Large Scale Dismantlement	Overhead & Ground-mounted Operations	Buried Waste Removal	Survey & Map Buried Waste
Long Term Strategy & Study for Site Conversion (Tasks19-22)									
19. Removal & Waste Management Strategy & Study		•							
20. Removal Technology Development	•	•	•	•	•				
21. Safe Confinement Strategy						•	•	•	•
22. Implementation of Confinement Strategy for FCM Removal						•	•	•	•

FCM = Fuel-containing material

d in Shelter Implementation Plan and from Shelter Staff Interviews

nd Interviews			System Classification by Size and Payload																
			Class I – Agile & Light Platform (10-100 Kg- Payload)					Class II – Medium-Scale (100-1000 Kg Payload)							Class III – Large-Scale Construction & Deconstruction (1000+ Kg Payload)				
Reconnaissance & Rescue Operation	Air Sampling	Dust Management	Platform Mobility	Sensor Platform/Rad Surveys	Sensor Platform/Visual Insp.	Small Coring	Sensor Installation	Platform Mobility	Route Preparation	Material & Equip. Transport	Site Preparation	Delivery Systems	Remote Construction	Structural Repairs	Material & Equip. Transport	Debris Handling & Removal	Site Preparation	Delivery Systems	Remote Construction
			I	I	I			II	II						III	III			
			I	I	I	I	I			II	II	II	II	II			III	III	III
			I	I	I	I	I			II	II	II	II	II			III	III	III
			I	I	I	I	I			II	II	II	II	II			III	III	III
			I	I	I	I	I			II	II	II	II	II			III	III	III
			I	I	I	I	I			II	II	II	II	II			III	III	III
•			I	I	I			II	II			II	II						
	•	•	I	I	I			II	II			II	II						
		•												II					
			I	I	I								II	II					
			I	I	I									II					
			I	I	I				II										

nd Interviews			Class I - Agile & Light Platform (10-100 Kg- Payload)					Class II - Medium-Scale (100-1000 Kg Payload)							Class III - Large-Scale Construction & Deconstruction (1000+ Kg Payload)				
Excavate & Sort Overburden	Package Contaminated Soils		Platform Mobility	Sensor Platform/Rad Surveys	Sensor Platform/Visual Insp.	Small Coring	Thermal Mapping	Platform Mobility	Route Preparation	Material & Equip. Transport	Site Preparation	Delivery Systems	Remote Construction	Structural Repairs	Material & Equip. Transport	Debris Handling & Removal	Site Preparation	Delivery Systems	Remote Construction
			I	I	I	I	I	II	II	II	II	II							
•															III	III	III	III	III
•	•														III	III	III	III	III

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Abbreviations and Acronyms

ALARA	as low as reasonably achievable
ChNPP	Chornobyl Nuclear Power Plant
DAWP	Dual Arm Work Platform
DOD	U.S. Department of Defense
DOE-NE	U.S. Department of Energy Office of Nuclear Energy, Science and Technology
DOE-NN	U.S. Department of Energy Office of Nuclear Nonproliferation
DOF	degrees of freedom
EBRD	European Bank for Reconstruction and Development
EPO	engineering performance organization
FCM	fuel-containing material
G-7	Group of Seven Nations: Britain, Canada, France, Germany, Italy, Japan, and the United States
HMI	human-machine interface
ISTC-Shelter	Interdisciplinary Scientific and Technical Center-Shelter
LLNL	Lawrence Livermore National Laboratory
MACS	Mobile Automated Characterization System
NRA	Ukrainian Nuclear Regulatory Administration
NRC	U.S. Nuclear Regulatory Commission
PMU	project management unit
PNNL	Pacific Northwest National Laboratory

RCS	remote characterization systems
SIP	Shelter Implementation Plan
TACIS	(a European Community program of) Technical Assistance to the Commonwealth of Independent States
TSEE	Teleoperated Small Emplacement Excavator

Contents

Figures

Tables

1.0 Introduction

The United States and participating Group of Seven (G-7)[a] countries are supporting nuclear safety upgrade efforts in Eastern Europe with a primary focus on placing the Chornobyl Nuclear Power Plant (ChNPP) Unit 4 Shelter in a stable and environmentally acceptable condition. The Shelter was hastily built in November 1986 to provide some containment for the ChNPP Unit 4 reactor, which had suffered massive damage in the April 1986 disaster. The Shelter environment poses significant risks to personnel from both radiological and industrial safety hazards. Technical experts in Ukraine have identified the lack of remote systems technologies, especially robotics, as a key problem hindering progress in needed investigations and remediation work.

The U.S. Department of Energy Office of Nuclear Energy (DOE-NE) is sponsoring work on the Shelter. DOE has undertaken a series of "Chornobyl Shelter Initiatives" to support international efforts to stabilize conditions at the Shelter and to reduce the risk of additional environmental consequences from this facility.

This report describes a needs assessment conducted to evaluate the requirements for remote systems, including robotics, at the Shelter. Remote systems encompasses the areas of deployment platforms, manipulation systems, sensors and other equipment that is remotely operated to remove the operator from direct exposure to hazardous conditions. This report will focus heavily on the discussion of deployment platforms and capabilities that were identified as needs. This document is intended to be used to identify remote systems needs and requirements at the Shelter and to provide general information on the conditions in the Shelter that could impact the use of remote systems. This document is intended as a source of information to assist those who will be implementing the Shelter Implementation Plan tasks. The document provides background information and general guidance on the application of remote systems. This document is not intended to define how to meet the identified needs. The requirements and specifications for systems will be defined in followon work.

A team of technical experts from Pacific Northwest National Laboratory, Lawrence Livermore National Laboratory, University of Tennessee – Knoxville, and RedZone Robotics[b] has participated in the needs assessment described here. The methodology applied included reviewing applicable documents pertaining to the Chornobyl Unit 4 Shelter and conducting interviews with subject matter experts in Ukraine and technical contributors who participated in the international team chartered to develop plans for stabilization and remediation of the Shelter.

(a) G-7 is the Group of Seven industrialized nations: Britain, Canada, France, Germany, Italy, Japan, and the United States.

(b) RedZone Robotics, Inc. is a private firm in Pittsburgh, Pennsylvania. It is affiliated closely with Carnegie Mellon University.

1.1 Background

The accident at Chornobyl Unit 4 on April 26, 1986, resulted in a series of unprecedented scientific and technical challenges, not only in the immediate response to the crisis, but continuing on to the present. The damage to the reactor building was extensive – the reactor core was completely destroyed (including the upper, lower, and lateral biological shields). Within the reactor building there was extensive damage, for example, the roof and upper building structures were completely destroyed and many major subsystems (e.g., pumps, coolant systems) were heavily damaged (see Figure 1.1).

The accident was precipitated by a series of events leading up to the explosion and subsequent fire in the reactor buildings at the Unit 4 reactor at the ChNPP located in Ukraine. On the night of the accident, reactor operators were conducting a test to see how long the generators would run without power. For this purpose, they greatly reduced the power being produced in the reactor and blocked the flow of steam to the turbogenerator (see Figure 1.2). Subsequent reviews of the accident determined that inadequate evaluation

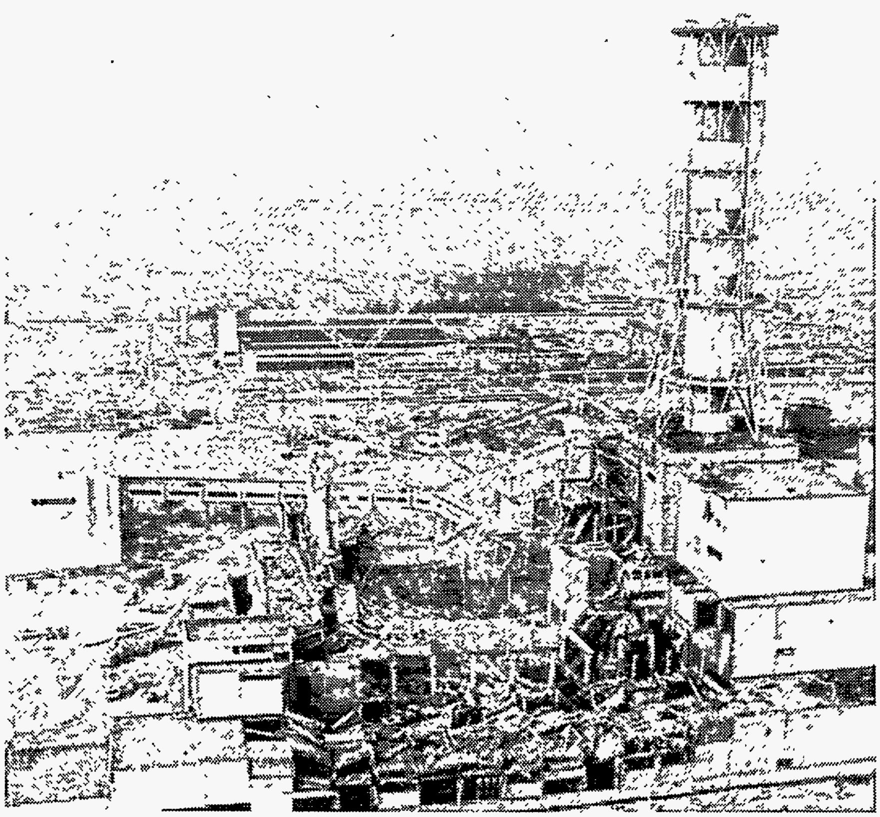

Figure 1.1. Destruction of Chornobyl Nuclear Power Plant Unit 4 from 1986 Explosion

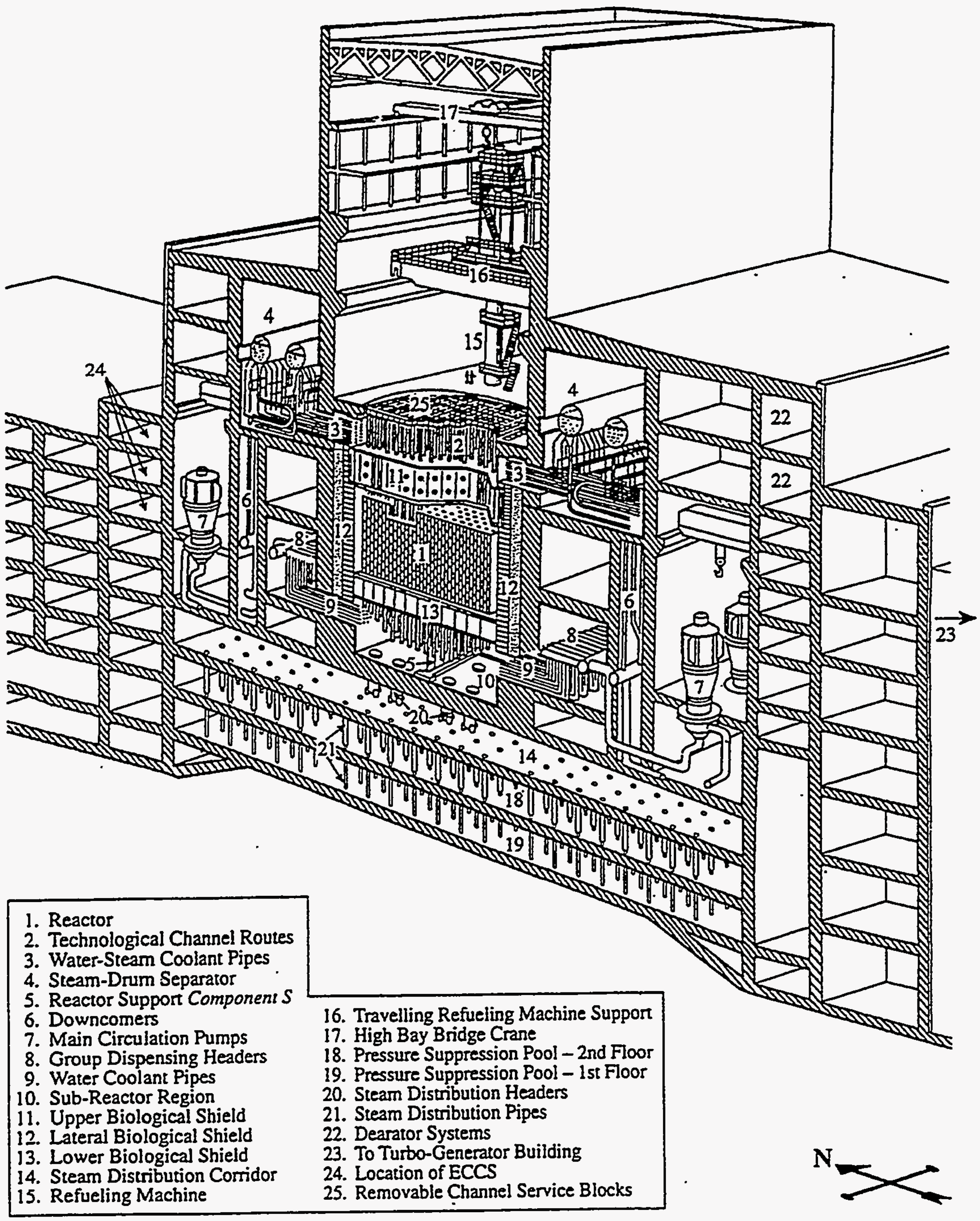

Figure 1.2. Sectional View of Chornobyl Unit 4 (a second-generation RBMK-1000 reactor) Prior to Accident (Sich 1994)

of the potential safety implications of such a test, insufficient safety features, failure to follow procedures, and a fundamental design flaw in the RBMK-1000 reactor design[a] contributed to this accident (Lederman 1996). The RBMK reactor design was unstable at low power due to the positive void coefficient; in this mode of operation any spurious increase in the production of steam can boost the rate of energy production. If that extra energy generates still more steam, the result can be a runaway power surge, which is what occurred at Unit 4.

At 1:23 a.m. on April 26, an operator pressed a button to activate the automatic protection system. This action was intended to shut down the reactors, but by this time it was too late. Within three seconds, power production in the reactor's core surged to 100 times the normal maximum level and there was a drastic increase in temperature. The result was two explosions that blew off the 2,000-metric-ton upper biological shield sealing the top of the reactor (see Figure 1.3). These explosions destroyed the building housing the reactor and spewed large amounts of radioactive fuel and contaminants in the vicinity of the plant; radioactive contamination from this accident was detected around the globe, even in the farthest-reaching countries.

Despite heroic attempts to quell the ensuing fire, it continued for 10 days. In an effort to put out the fire and reduce the potential for criticality, large amounts of materials, including boron, were dropped by helicopters into the open void of the reactor building. Although these materials were not effective in stopping the fire, they have contributed significantly to problems in remediation of this accident.

Rising hot gases carried into the environment aerosolized fuel as well as fission products. The fuel consisted principally of uranium mixed with some plutonium created as a by-product of normal reactor operation. In addition to plutonium, the most dangerous isotopes in this airborne release included iodine-131, strontium-90, and cesium-137. A plume containing these radioisotopes moved with prevailing winds to the north and west, raining radioactive particles on areas thousands of miles away. Affected regions included Ukraine, Belarus, Russia, Georgia, Poland, Sweden, Germany, Turkey and other areas. Even the United States and Japan were able to read measurable levels of radiation from the accident. In Poland, Germany, Austria, Hungary, and Ukraine, crops and milk were so contaminated they had to be destroyed. In Finland, Sweden, and Norway, carcasses of reindeer that had grazed on contaminated vegetation had to be destroyed. The lingering toll of health effects from this disaster continues to affect the populations of these areas today.

Following the accident, immediate action was required to seal off the gaping crater created by the accident because it was a continuing source of airborne contamination. The post-accident containment strategy centered on the rapid construction of a structure called the "Shelter,"[b] which was completed in November 1986. This structure (Figure 1.4) represents an amazing architectural and engineering feat and

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(a) RBMK is a Russian abbreviation for Reaktor Bolshoi Moshchnosti Kipyashchiy. The RBMK is a Soviet-designed, graphite-moderated, boiling water-cooled, channel reactor.

(b) The Ukrainian term for the Shelter is "Object Ukritiye." This structure also is referred to as the "sarcophagus."

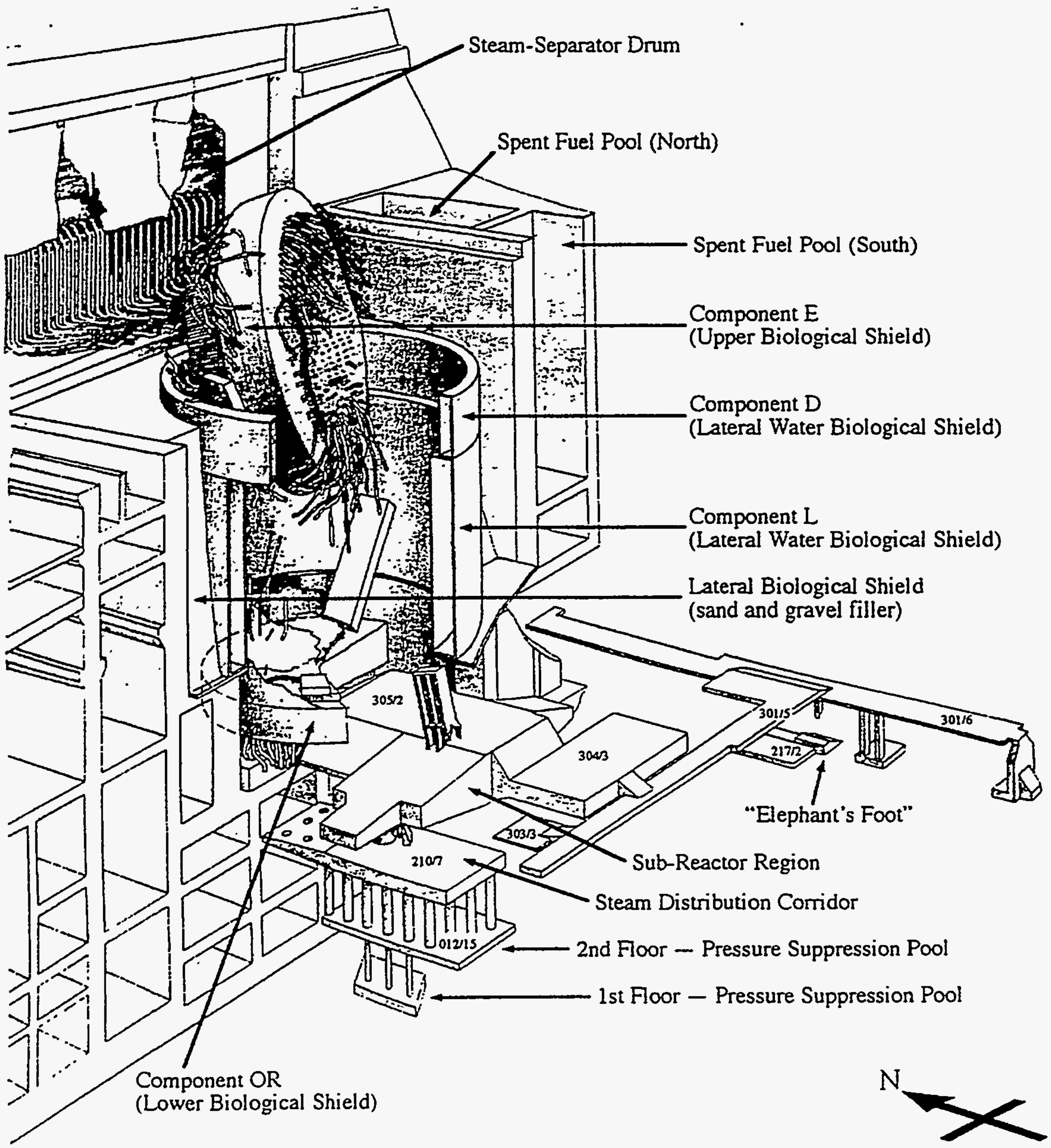

Figure 1.3. Sectional View of Chornobyl Unit 4 after Accident (Sich 1994)

is a monument to great sacrifices made by the "Liquidators" who were brought in to deal with the effects of the accident. An enormous effort was required to mount the clean-up operation. Decontaminating the ground and buildings, enclosing the damaged reactor, and building the Shelter were formidable tasks that were accomplished very quickly. Because of the crisis conditions under which confinement was achieved, a permanent structure was not built, and the Shelter is considered a provisional barrier. Because of the very high radiation levels, much of the construction was completed using remote methods and did not allow for the type of inspections and quality standards that would be applied in a normal construction

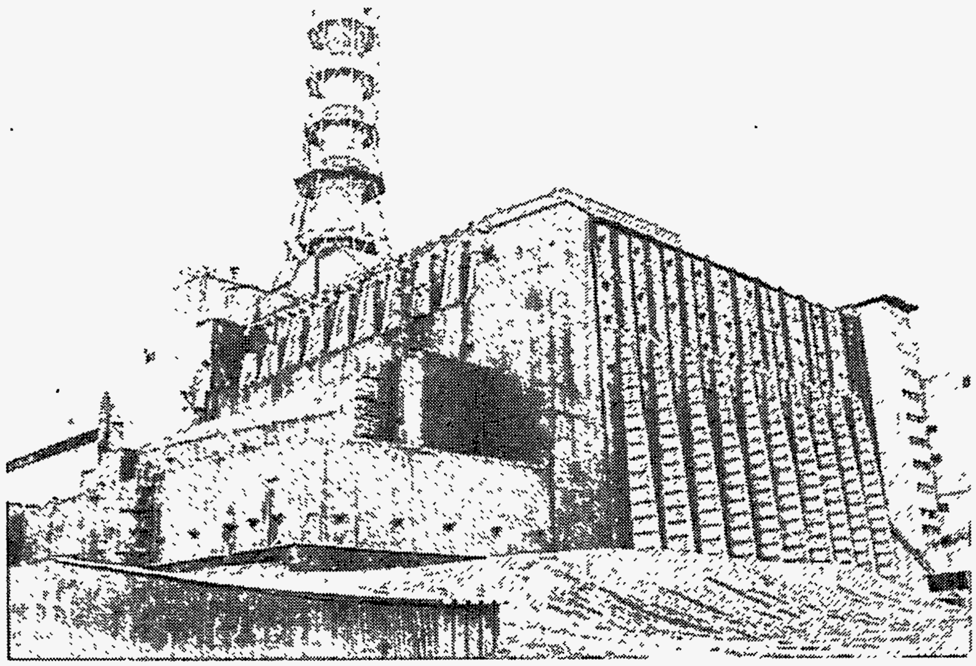

Figure 1.4. View of Shelter from Northwest Side

project of this magnitude. Therefore, many problems exist with the condition of this structure today, which have led to significant concerns about its structural integrity and projected life expectancy.

Since the accident and completion of the Shelter, primary efforts have been dedicated toward assessing the conditions in the Shelter and performing some remediation work to reduce immediate danger. For several years following the accident, a group of scientists affiliated with the Kurchatov Institute in Moscow conducted what came to be known as the Complex Expedition.[a] At great personal risk to their health, these scientists over a period of several years entered the damaged Unit 4 to determine the state of the remaining fuel and the risk of additional criticality events. Some of the accomplishments since the accident include locating the fuel remaining within the Shelter, ensuring that criticality could not be reestablished, ensuring the other operating units and their personnel were not affected by Unit 4, and monitoring the environment to ensure that fuel from the Shelter was not leaking.

(a) The challenges and discoveries made by these scientists are documented in two very compelling video programs. The first, produced by the BBC Horizon Program, is "Inside Chernobyl Sarcophagus" and the second, produced by the U.S. Public Television Program NOVA, is "Chernobyl: Mission to Suicide."

The most important finding of the Complex Expedition was the discovery that the fuel had melted and mixed with the serpentine[a] material from the surrounding shield to form lava-like flows into the piping and rooms below the reactor vessel.

Computer-controlled sensor equipment has been installed and is monitoring such parameters as gamma radiation, neutron flux, temperature, heat flux, and concentrations of hydrogen, carbon monoxide and water vapor in the air. Other sensors monitor the mechanical stability of the structure and the fuel mass so that any vibration or shifts of major components can be detected. Some systems for criticality control also are in place and are currently in the process of being upgraded through a joint initiative between ChNPP and the U.S. effort to enhance the safety of workers involved in Chornobyl Shelter cleanup efforts. Criticality control measures include providing systems to monitor conditions, to inject neutron poisons if needed to prevent nuclear criticality, and to pump out excess water leaking into the Shelter.

High radiation levels, airborne contamination, and structural damage leading to access restrictions make the work difficult or impossible in some areas. Available information is not comprehensive and is generally not felt to be sufficient to adequately assess the conditions or risks related to the Shelter. Personnel performing work within the Shelter are often exposed to high radiation levels and extreme industrial hazards. There was also concern for the safety of workers at the other reactor units at the plant, Units 1, 2, and 3. Unit 2 was shut down in 1991. Unit 1 was shut down in 1996. Unit 3, which is adjacent to Unit 4, is scheduled for shutdown in 2000. About 7,000 employees of ChNPP still work at the Chornobyl facility.

As mentioned before, there are significant concerns regarding the Shelter structure. In constructing the Shelter, some of the supporting beams for the enclosure were installed on the original Unit 4 building structures. There is significant concern that these support components in the original building may have been structurally compromised by the accident conditions and their failure could cause the shelter roof to collapse. This situation is aggravated by the corrosion of internal metal structures. The atmosphere within the Shelter has high humidity and a significant amount of water (both standing and flowing) from rain and snow leaking into the structure. The Shelter was not designed to withstand earthquakes, and the Chornobyl area of Ukraine is a known area of seismic activity.

1.2 Development of the Shelter Implementation Plan

In 1991, the Chornobyl Shelter Organization realized the urgent need for stabilization and issued an International Call for Proposals for the development of a new structure, called "Shelter-2" (Ukraine Academy of Sciences [UAS] 1992). Some 300 proposals were submitted in response to this call, including a proposal emphasizing remote systems approaches to stabilize, then build a second structure. This proposal, led by Oxford University with Lawrence Livermore National Laboratory (LLNL) as a team partner, was ranked highly in the competition (seventh place) and was selected for formal presentation, but was not selected for award. The successful proposal, from a consortium of two English and two French

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(a) Serpentine materials are any of a group of greenish, brownish, or spotted minerals, $Mg_3Si_2O_5(OH)_4$, used as a source of magnesium and asbestos.

companies (the Alliance Consortium), was awarded a $10-million contract to complete a feasibility study for Shelter-2. The recommendations from this study ultimately were rejected on the grounds of enormous cost, the failure to deal effectively with the problem of fuel removal, and the lack of a remote systems approach.

Subsequently, in 1996, a study was completed by TACIS (a European community program of Technical Assistance to the Common Wealth of Independent States) detailing concepts and cost analyses of five identified scenarios for the decontamination and decommissioning of Chornobyl. This work resulted in development of *Chornobyl Unit 4 – Short and Long-Term Measures – Final Report* (TACIS 1996). In December 1996 and February 1997, representatives of the G-7 Nuclear Safety Working Group met with representatives of the Government of Ukraine in Washington, D.C., and completed an agreement in principle to proceed with in-depth studies to implement the recommended approach presented in this study. It was determined that a team of technical experts under G-7 sponsorship would develop an integrated Shelter Implementation Plan.

This G-7 Nuclear Safety Working Group team developed the comprehensive plan *Chornobyl Unit 4 Shelter Implementation Plan* (Kessler and Kostenko 1997). The implementation plan recognizes the need for remote systems technologies to perform a number of the tasks outlined in the plan. The remote systems needs identified in the Shelter Implementation Plan are described in Chapter 3 of this report. The estimated costs and schedule for the Shelter Implementation tasks are summarized in Appendix C.

1.3 Overview of this Report

This report provides a compilation of the findings and recommendations on specific near-term activities that could be undertaken to provide needed systems and technologies as described in the Shelter Implementation Plan and by Shelter Operations staff.

Chapter 2 describes current Shelter operation and conditions and details remote technology needs from the perspective of the Shelter Operations staff. Chapter 3 describes the tasks and remote systems needs outlined in the Shelter Implementation Plan. Chapter 4 is a comparison and composite analysis of all of the remote system needs described by the Shelter Operations staff and in the Shelter Implementation Plan. Chapter 5 discusses cost-benefit perspectives and approaches for deploying remote systems at the Shelter, describes examples of types of remote systems that could be applicable to the needs of ChNPP, discusses current practice with remote systems at the Shelter, and describes current ongoing remote systems development efforts related to the Shelter and lessons learned from other remote systems development efforts. Chapter 6 describes the infrastructure needed for development and deployment of advanced remote systems and discusses the need for a central remote technology systems center. Chapter 7 provides recommendations and conclusions. Chapter 8.0 and 9.0 list the references and bibliography.

2.0 ChNPP Unit 4 Shelter Operations Conditions and Needs

Section 2.1 of this chapter describes the organizational and physical conditions affecting the Shelter. Section 2.2 describes remote technology system needs identified by Shelter Operations staff. Information presented in this chapter was obtained through interviews with subject matter experts at the Chornobyl Shelter and supporting technical institutes.

2.1 Organizational and Physical Conditions Affecting the Shelter

Section 2.1.1 describes the organizational and regulatory considerations affecting the Shelter and Section 2.1.2 describes physical conditions affecting the Shelter to give some understanding of the constraints under which remote systems and other mitigation efforts would be deployed.

2.1.1 Organizational and Regulatory Considerations

Technology deployment must fit within the organizational structure and regulatory parameters pertaining to the Shelter. Section 2.1.1.1 describes the Shelter Operations' organizational hierarchy and the influence of other organizations within and outside Ukraine. Section 2.1.1.2 describes the evolving growth of a regulatory structure in Ukraine and its influence on Shelter operations.

2.1.1.1 Organizational Infrastructure

The Industrial Association Chornobyl Nuclear Power Plant (ChNPP) oversees and conducts activities at Chornobyl Unit 4. The Interdisciplinary Science and Technology Center "Ukrytie" (ISTC-Shelter) is the main contractor for ChNPP to perform research and development for the Shelter. All work within and in support of the Chornobyl Shelter is performed primarily by these organizations. ChNPP is the state-run utility that is responsible for the entire site including the operating reactor (Unit 3) and the three reactors which have been shut down (Units 1, 2, and 4) and are currently being decommissioned. The ChNPP Unit 4 Shelter Operations department is a separate unit that plans and conducts the day-to-day activities at the facility. The Shelter Operations director also is deputy general director of the ChNPP, who reports to the general director of the ChNPP.

The ISTC organization is the technical leader for the Chornobyl Shelter, providing engineering and scientific support and resources. The ISTC-Shelter organization is affiliated with the Kurchatov Institute in Moscow, and some of the scientists hold positions at both institutes. During visits to the site, the needs assessment team conducted interviews with representatives of both the ISTC-Shelter and Shelter Operations (see Appendix A). The ISTC provides technical support to operational research missions at the Shelter for which it is tasked. Assignments might include support to ongoing operations such as the measurement of radiation fields at locations within the Shelter, verification of sensor reliability, or evaluation of a criticality safety issue. The ISTC has significant expertise in nuclear safety as well as in sensors, monitoring, and robotics manufacturing. In addition to its direct support role, the ISTC also provides indirect support such as training for operational personnel (in the Shelter Operations unit) and technical support in nuclear safety and other areas of expertise, including development of robotic equipment.

The ISTC operates several chemical analysis laboratories where analyses of samples from the Shelter are performed. The ISTC offices are in the town of Chornobyl located within the 30-km exclusion zone. The facilities are old with few of the basic infrastructure resources that would be found in Western facilities of this nature. However, even with its very limited resources, this organization is able to provide valuable hands-on support to the Shelter Operations organization in actual deployment of equipment in the Shelter.

The Shelter Operations unit has direct responsibility for day-to-day operations at the Shelter. It is responsible for ongoing investigations, maintenance of the structural stability of the Shelter, dust suppression, and monitoring systems. Shelter Operations, in concert with the ISTC, performs evaluations on the location and quantity of fuel-containing materials (FCM), modification of systems for dust suppression and other functions, and facility modifications to improve access within the shelter. Shelter Operations is broadly responsible for infrastructure requirements related to operations at the facility.

Shelter Operations maintains, operates, and adapts all equipment used at the shelter with technical support from the ISTC. In addition, it reviews, evaluates, and makes selection decisions for externally (and internally) funded projects at Chornobyl. In the near future, a new "Project Management Unit" (PMU) will be selected to support Shelter Operations and the European Bank of Reconstruction and Development (EBRD) in implementing the Shelter Implementation Plan (SIP) tasks. Following award of any such work, this PMU will provide project management to oversee work at the Shelter.

The U.S. Department of Energy, in conjunction with the U.S. Department of State and the Ukrainian government, is supporting the development of the Chornobyl Center, which is headquartered in Kyiv but has a laboratory division located closer to the ChNPP site in Slavutych.

2.1.1.2 Regulatory Interface

The following discussion is based on information provided during an interview with Dr. Igor Symonov,[a] a subject matter expert in the area of nuclear regulation in Ukraine. The government of Ukraine is developing the required infrastructure and requirements for providing regulatory oversight and licensing of nuclear facilities and operations. With the breakup of the Former Soviet Union, most of the regulatory bodies and processes were retained in Russia, and Ukraine now is faced with establishing its own national programs. The Ukrainian Nuclear Regulatory Administration (NRA) has been established to perform an oversight and licensing role similar in nature to the U.S. Nuclear Regulatory Commission (NRC). The NRA has sought advice from the NRC to develop a strong program in Ukraine to oversee the safety of nuclear facilities. There has been an effort to pull together the remaining technical specialists within Ukraine into one center to preserve these resources and make the best use of their technical talent. The State Scientific and Technical Center is an independent institute at which many of these technical specialists now are employed. These specialists are contracted by the NRA for nuclear safety support and technical expertise for review and oversight in a broad range of technical areas. This organization is also heavily involved in the formulation of nuclear regulatory programs and guidelines for Ukraine.

The regulatory programs being established by the NRA primarily deal with the oversight and safety of operating nuclear facilities. Policies and procedures are being defined and implemented. Since the Chornobyl Shelter is a state problem, the NRA has been involved in developing a statement of policy on the Shelter. This statement of policy will serve as an interim measure to direct the regulatory requirements because the Shelter is so much outside the bounds of normal nuclear operations, it is currently exempted from most of the regular rules that apply to operating nuclear plants. It is clear that safety measures must be implemented to ensure the protection of the workers, the public, and the environment; however, this will take time to evolve. The NRA wants the facility transformed to a safe state and, in particular, they must develop suitable regulations to guide this. Under normal circumstances, an applicant for licensing would send documentation to the NRA for review. This process will need to be altered to develop a customized program for the Shelter that will be applied in reviewing and commissioning individual remediation projects.

The NRA will establish regulatory milestones for each of the tasks in the Shelter Implementation Plan. Because of the level of hazards and the condition of the Shelter facility, the NRA believes these milestones should be more frequent than for a normal plant process. One of the first milestones should be agreement on technical requirements and specifications. Next there would be agreement on the conceptual design, and then detailed design approval. In developing programs and testing prototypes or concepts, the regulatory involvement would be limited to reviews of the technical scope of work. This review would ensure that appropriate safety considerations are included in the test plans. The process envisioned is that a technical point of contact from the regulatory organization would be assigned to a

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(a) Dr. Symonov is Science Director of the State Scientific and Technical Center on Nuclear and Radiation Safety under the Ministry of Environmental Protection and Nuclear Safety of Ukraine.

project and actively participate in review of the documentation as it is developed. This person would be requested through the operating organization for which the work is being performed. This will ensure that the system will meet the requirements in the future and streamline approvals. At the Shelter, Mr. Artur Korneev, Deputy Director of Shelter Operations, should be the one to request assignment of the safety officer as individual projects begin to develop requirements and designs.

To ensure approval for deployment of a remote system, the safety and regulatory reviewer should participate in the following areas. This is consistent with the Shelter Implementation Plan (Chapter 10).

1. system requirements and specification review

2. review of conceptual design and agreement in principle (milestone)

3. review of detail design and authorization to proceed (milestone)

4. review of test program and planning documents

5. authorization for commissioning and operation.

As a guideline, projects should plan to allocate about 2% of their budget for regulatory reviews and approvals. The regulatory process and its associated costs should be carefully considered in planning remote systems projects for the Shelter.

2.1.2 Physical Conditions

This section describes the meteorological, structural, physical, and radiological conditions at the site.

2.1.2.1 Geographical and Meteorological Conditions at the Site

The ChNPP site is located on an industrial site in the Chornobyl district of Ukraine. The site is located approximately 15 km to the northwest of the town of Chornobyl. The meteorology of the region is summarized in Table 2.1 (UAS 1992).

The ChNPP site is in a seismically active region. Damage to the Shelter from an earthquake is considered to be a significant risk. "According to data supplied by the Ukrainian Academy of Sciences Institute of Geophysics, the intensity of seismic influence on the ChNPP site may be up (to) magnitude six according to the Richter scale and with the account of the technogenic changes of the ground conditions, the seismic danger may be up to magnitude seven" (UAS 1992, p. 11).

2.1.2.2 Structural Condition of the Shelter

The Shelter was constructed quickly between the accident in April 1986 and November 1986 to enclose the damaged structures (UAS 1992, pp. 19-28). This was an enormous construction effort

Table 2.1. Meteorology of Chornobyl Region of Ukraine

Coldest month	January, average temperature is –5.6°C
Warmest month	July, average temperature is 19.1°C
Min/Max projected	-44.9°C to 42.2°C
Annual relative humidity	77%
Daily maximum precipitation	190 mm
Maximum 20-min. precipitation	72 mm
Days of snow cover/average depth	90 to 102 days; 8 cm
Average wind velocity	4.2 m/s
Maximum wind velocity	47.3 m/s
Tornado probability/speed	$3*10^{-6}$; 72 m/s rotation; 18 m/s translation

performed in extremely dangerous conditions. Thousands of "Liquidators" were brought in to support the massive undertaking of cleaning up the area and constructing the Shelter structure.

A number of large concrete walls and structures were poured both to support the structure and encase areas containing large amounts of highly radioactive debris. The primary supporting structures for the Shelter are the Monolith Wall on the west side of Unit 4 that remained intact following the accident, a new Cascade Wall built on the north side of Unit 4, two Ventilation Shafts on the east side of Unit 4, supports (Mammoth, B1 and B2 beams) resting on destroyed stacks on the south side of Unit 4 (see Figure 2.1).

To buttress the heavily damaged de-aeration stack, new separating and supporting walls were constructed in the turbine room. A steel disc-cover to prevent horizontal displacement also was installed. These new supporting structures are intended to stabilize the structure and transmit loads from the building to the ground.

A new roof was built to cover the Shelter. The roof consists of 27 metal tubes 34.5 m long. Girders installed across the central hall support these tubes. A roof constructed of shaped plates is installed over the tubes (see Figure 2.2). This roof is not completely sealed, and leaks allow large amounts of water from rain and snow into the Shelter. Repairs of some sections have been undertaken to reduce the ingress of moisture.

The long-term strength and stability of the structural supports over time are believed to be limited. The nature of the construction of the Shelter prevented the use of welded joints or bolts in the installation

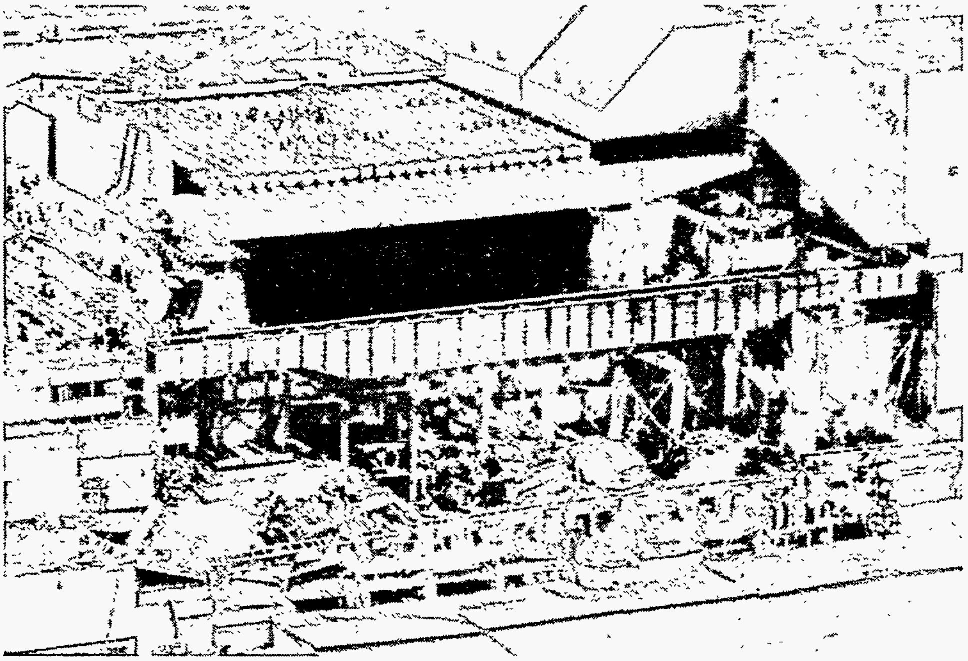

Figure 2.1. View of Mammoth Beam and Roof Beams

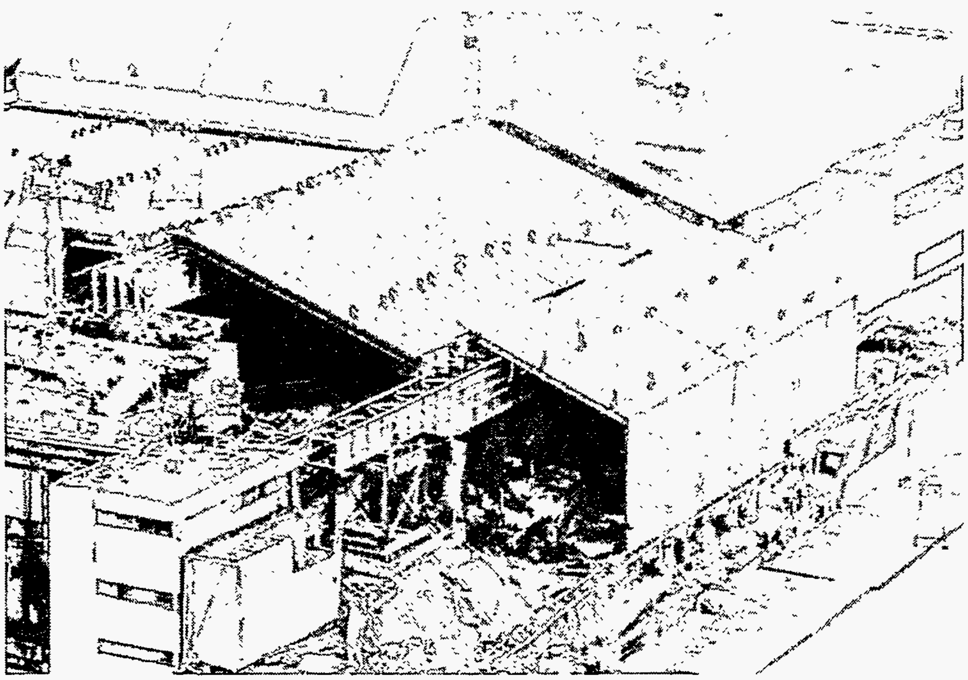

Figure 2.2. Later Stages of Roof Construction

of the supporting structures. Exact positioning and anchoring also was not possible. Currently it is not possible to perform inspections of these structures, which is a top priority for the application of remote systems. Some anti-corrosive coatings were applied prior to construction, but there is no way to maintain this coating. Therefore, eventual degradation of the structural steel is inevitable. Acidic liquids formed from water that has leaked into the Shelter and mixed with the materials dispersed to douse the fire, as well as some of the dust suppressions solutions, are also contributing to the degradation of structural materials.

2.1.2.3 Physical Conditions and Radiation Levels within the Shelter

During the accident the reactor core, walls and ceiling of the reactor hall, de-aeration stack, turbine hall, and other structures in the steam separation drum area were severely damaged or completely destroyed. Significant displacement of the main building support structures occurred. In some areas, structural displacements ranging from 900 mm to 1,000 mm have been measured. Cracks in the supporting structures 100 mm to 150 mm wide have also been measured. The emergency cooling system was completely destroyed and many areas were buried by collapsing debris from other structures. The reactor lid (often referred to as "Elena") with its attached piping fragments was thrown off and came to rest at a 15° angle in the reactor vessel (see Figure 2.3). The reactor base (lower biological shield) was displaced to a position 4 m lower than its original position. This was subsequently determined by the Complex Expedition to be the area where the melting fuel and the serpentine filler material (made up of

Figure 2.3. View of Unit 4 from Southeast Showing Reactor Lid and Central Hall

coarse sand, pebbles, and small rocks) combined and flowed out as the lava-like masses that are now distributed in various areas below the reactor vessel (Borovoi and Sich 1995).

The large crater created in the Central Hall is filled with debris from the explosion and fire-retardant materials dropped from helicopters. These piles of debris rise to 15 m in some areas, creating significant challenges for the deployment of remote equipment. During construction of the Shelter, a significant amount of concrete penetrated into the reactor pit and the rooms below. This has created additional areas of obstruction and total blockage of some passageways.

Because the Shelter is not environmentally sealed and has no existing infrastructure to provide environmental controls, the weather can be expected to have a significant impact on the daily conditions within the Shelter. Significant levels of moisture and variations in temperature can be expected to affect the working conditions and requirements for equipment to be used within the facility. Video footage taken by Shelter Operations clearly demonstrates the effects of the environment, showing very cold conditions and dripping water.

Some level of heat is generated by the FCMs, but it is dispersed by the relatively steady airflow through the Shelter. Extreme elevations of temperature are not considered to be a problem, as long as the Shelter does not collapse and normal air flow is maintained. The levels of heat releases estimated from the fuel decay, disregarding enrichment of cesium isotopes, are shown in Table 2.2 (UAS 1992, p. 37).

During the accident, fuel in various forms was scattered throughout the areas inside the Shelter. Fuel fragments and rods were thrown from the reactor core. The bulk of this expelled fuel is concentrated in the Central Hall (Reactor Hall) or outside the building in the area now covered by the Cascade Wall. A small amount of the core material still remains within the reactor vessel. Tons of finely dispersed fuel dust can be found throughout the Shelter. This material is highly radioactive and easily mobilized by the air currents within the facility. Efforts to minimize the spread of this dust have focused on applying spray fixatives. This dust can be also become entrained in the water flows and some is moving about the Shelter in this manner.

Table 2.2. Heat Releases from Fissile Decay (UAS 1992)

Release Estimate as of:	Rate of Energy Release (kilowatts per ton)
January 1990	0.75 kW/t
January 1991	0.55 kW/t
January 1992	0.40 kW/t
Projected 1993-1997	0.4 – 0.3 kW/t

As mentioned earlier, the melting fuel from the reactor core combined with the serpentine material that was located in the lateral shield around the reactor vessel. This formed lava-like flows that spread to various locations in the Shelter and solidified (see Figure 2.4). Estimates of the amounts of fuel in

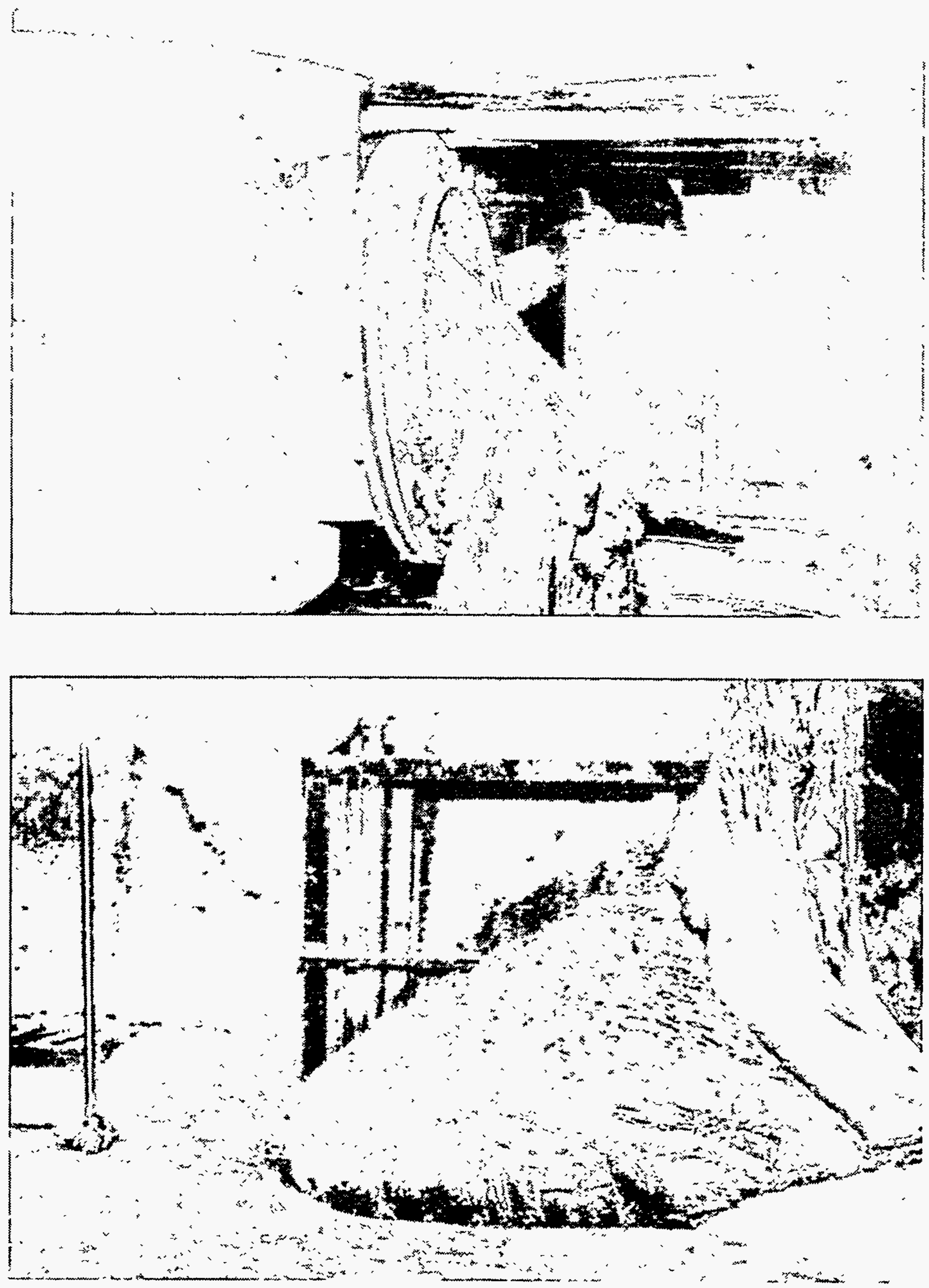

Figure 2.4. Interior Views Showing Solidified Melted Fuel Covering Corridors

various locations are shown in Table 2.3 (UAS 1992, p.27). Analysis shows this material contains finely dispersed fuel particles impregnated in a silicon-based matrix (Pazukhin 1996). Previous attempts to remove this material showed it to be very hard.

The total amount of radioactivity estimated in the Shelter in 1992 was 20 MCi (UAS 1992, p. 34). Most areas of the lower rooms of the facility, except those areas containing FCM flows, have relatively low radiation dose levels in the range of 1R/hr. In areas of the Central Hall, radiation levels are much higher and vary considerably, ranging from 10 to 2,400 R/hr. It is estimated that in 70% of the premises the gamma radiation levels do not exceed 0.1 to 1.0 R/hr. The radiation levels in the Turbine Hall at elevation 12.5 m range from 0.5 to 2.5 R/hr. Radiation levels on the roof range from 6 to 46 R/hr, but may have been reduced by subsequent mitigation efforts. Radiation levels in the areas directly surrounding the outside of the Shelter vary from 15 to 300 mR/hr, with some hot spots in the western area reaching 1 to 5 R/hr (UAS 1992).

The prevailing opinion of scientists studying the FCM conditions is that these materials exist in a subcritical state. However, some recently recorded deviations of neutron sensor readings have caused concerns about criticality in the Shelter. Current initiatives are underway to improve the quality of neutron monitoring equipment in the Shelter.

The spread of radiation, as airborne contaminants, is a primary concern in the scenario of a potential collapse of the Shelter. Some airborne release of contaminated dust occurs on a routine basis through the

Table 2.3. Estimated Dispersion of Fuel within Shelter

Location	Elevation, Meters	Uranium Fuel Weight, tons
First floor bubbler pool	0.00	1.5
Second floor bubbler pool	3.00	11.5
Steam distribution corridor	6.00	23.0
Sub-apparatus room	9.00	75.0
Corridors and rooms with lava 304/3, 303/3, 301/5, 301/6	9.00	20.0
Other concentrations of fuel-containing materials	0.00-9.00	4.0
Total		135.0

existing openings in the Shelter. These openings are estimated to have a total combined area of 1,000 m^2. The release of contaminants is estimated to be less than 0.3 Ci/yr for Cs-137 and $3*10^{-3}$ Ci/yr for plutonium and other transuranic isotopes. The degradation of the FCM materials into dust particles and dissolution or leaching of uranium compounds and other radionuclides in water flows may cause contaminant releases to increase over time.

2.2 Remote Technology Needs Defined by Shelter Organizations

This discussion of remote technology requirements is based on detailed discussions that were held by the assessment team with representatives of the Shelter Operations and ISTC-Shelter organizations. Mr. Artur Korneev, Deputy Manager of Shelter Operations, provided an operating staff perspective on key issues and priorities, as well as invaluable perspectives on the working environment and traditional engineering approaches. Mr. Alexander Ivanov, Nuclear and Radiation Safety Department Director at ISTC-Shelter, provided a technical perspective from the primary institute supporting the Shelter. The requirements identified by these organizations are summarized below.

Previous experience in the use of robotics at the Chornobyl Shelter has been mixed. In the active phase of response to the original accident, Russian and European robotics technology was used to perform tasks in high radiation fields. Three automated systems, best described as small, automated bulldozers, were used to move debris from the Unit 4 roof into the reactor chamber. Each of these systems worked for a few days, but then became inoperable. The complexity of the automated systems and the harsh operating conditions resulted in the failure of the systems due to accumulated radiation damage. Entanglement of the vehicles in the debris was another significant problem that immobilized a number of systems. Removal of these failed systems often resulted in significant worker exposure. During construction of the Shelter, remotely operated tanks or construction vehicles were used to move earth or carry and emplace heavy loads, such as shielding material. These applications are best referred to as crude teleoperated systems that were not truly automated. The Complex Expedition scientists made a number of attempts to deploy remote systems, including a remotely operated toy tank with a video camera strapped to it. Their efforts met with limited success, due to the challenges of getting the systems into the areas required to perform the work. Again, radiation damage to electronics was a major problem.

Based on these experiences, Mr. Korneev and the assessment team have identified several key operational issues related to remote technology deployment. The first is the need to initially focus on simple, reliable, and robust remote systems. In addition, a stepwise modular approach should be taken to build confidence and experience with automated technologies. Finally, off-the-shelf equipment that is inexpensive, reliable, and proven should be used wherever possible. If the Shelter Operations staff choose to utilize remote technology to deal with more complex tasks, they will face changes in the style of their remote operations. This may include using more advanced systems with sophisticated computerization and electronics to perform more tasks with greater ranges of motion; however, the added complexity will mean that more pretesting and operator training will be required.

Mr. Korneev stressed the need for a number of remote technologies, not just robotics, to enable his staff to perform necessary operations in the Shelter. These systems can reduce the exposure of personnel to hazardous conditions in the Shelter and enable them to perform work in previously inaccessible areas.

During the discussions Mr. Korneev identified the following areas where remote systems could be applied:

- Structural assessment and stability: Conduct inspections and install sensors to monitor and determine the integrity of construction structures and perform stabilization activities.

- Monitoring: Install and monitor radiation measurement and criticality monitoring sensors. Track water and airborne contamination pathways through the Shelter and support water mitigation and dust suppression measures.

- Shelter access and debris removal: Clear pathways to provide access for personnel and equipment by removing contaminated debris, decontaminating areas, and installing temporary shielding.

- Fuel investigations: Determine the amount, configuration, and physical properties of the fuel and fuel containing materials in the Shelter.

- Buried waste removal: Locate, retrieve, segregate, and package buried waste around the Shelter.

These areas of remote technology needs are further described below.

2.2.1 Structural Assessment

The top priority activity is the investigation of the structural integrity of the Shelter, due to concerns about the potential for collapse and release of airborne contamination. NIISK, the Research Institute of Building Construction, a Kyiv-based institute over construction structures, has done some preliminary work in this area. Starting in 1986 diagnostic efforts and geodesic surveys were initiated to monitor the settling and inclinations of the Shelter. NIISK provided a list of those structures that need to be investigated. These include

- the supports under the "B1" and "B2" beams of the Shelter roof

- the supports under the Mammoth beam

- the roof structure

- the floor of the under-reactor room.

The "B1" and "B2" beams support the roof and were installed remotely during Shelter construction. The eastern ends of these beams rest on vertical ventilation shafts from the original structure. The condition of these shafts is unknown, both with respect to the explosion during the accident and also subsequent detrimental effects of the radiation since the accident. On the western end, steel supports were added to the Western Wall where the beams rest. Assessment of the structural condition of these beams is desired. Unfortunately, these areas are challenging to assess using a ground-operated remote system because the Central Hall area is cluttered with large debris (1-2 m^2) and has very high radiation levels. Many of these areas are located at higher elevations that would be difficult to access from a ground-based vehicle. Remote inspection would either require a different approach or an extended campaign to clear a path or install access structures to these locations. One approach to meeting height and reach requirements, depending on the task and pay load, is to use devices such as a telescoping tower assembly, telescoping pneumatic tubes, or articulated booms.

Short-term stabilization efforts are also considered to be a high priority. In particular, reinforcement of the ventilation stack is a top priority with work already underway to address this problem. Also, cutting and welding activities along the roof are needed to close off areas where water is currently entering the Shelter. These stabilization activities are considered to have a high dose uptake potential if activities are performed manually; therefore, they are good candidates for application of remote systems.

There are some concerns that the large upper biological shield, which is lodged in the reactor cavity, could drop due to degradation of supporting structures. There is debate over the potential for this happening and the extent of damage from such an event. Further investigations are needed and possible installation of alternate supports.

2.2.2 Monitoring

A set of monitors has been installed to provide real-time feedback on parameters of interest such as temperature, humidity, gamma radiation, and neutron fields at key areas within the Shelter. These monitors are permanently wired back to a central monitoring station; collected data is used to monitor conditions and detect dangerous conditions such as potential criticality. There is an ongoing need to maintain and upgrade this network, such as adding or replacing sensors or maintaining the cables running to them. This repair work is one potential application for remote systems. The ISTC has developed an information and measurement system they call "Finish," which electronically collects data from the installed sensors and transfers this information via a computer network to their facility in Chornobyl for data storage and analysis (Borovoi et al. 1996, pp. 128-139).

Another diagnostic task for remote systems is collecting data on radiation fields, temperature and humidity in radiologically dangerous areas within the Shelter, especially the under-reactor areas in Rooms 305 and 210 and within the Central Hall.

Remote diagnostic systems may be appropriate in two other primary areas of interest: dust and water management. Decay processes of the FCMs are causing extensive aerosolization of contaminated dust particles. This dust is then transported throughout the Shelter and contaminates other areas, or even exits the Shelter through the many air gaps present in the structure. Desirable applications for remote systems include 1) characterizing the amounts of dust and flow pathways by which it is dispersed throughout the

Shelter and to the outside environment and 2) locating and reducing this dust by coating surfaces with fixative agents.

A significant amount of water enters the Shelter from the outside environment and can flow through and pool in various areas. Because of the potential for criticality, management of this water flow is a high priority at the Shelter. Remote systems could be used to locate standing and flowing water within the Shelter to understand transport and evaporation patterns.

Mr. Korneev considers diagnostics and monitoring to be the primary areas for practical application of robotics inside the Shelter. His first priority in this area is to obtain lightweight reconnaissance systems that can maneuver over rough terrain and deploy a variety of sensing systems and tools to perform surveillance and characterization tasks.

Remotely operated sensing systems could be carried onboard or installed by the remote deployment system for radiation measurement, temperature sensing, criticality monitoring, structural measurements, visual inspection, sampling, mapping, and examination of air and water conditions.

One of the heavier tasks identified is the need to remotely drill boreholes to install sensors. Shelter Operations has done some drilling operations in the past, but has had difficulty controlling the drill bit, which often follows an unpredictable path. They are interested in having inclinometers to monitor the direction of the drill bits to better control the drilling operations and predict the path. They are currently working with a Ukrainian institute to develop prototype equipment to do this work. The institute doing this work is experienced with drilling for undersea mining. They also need to perform drilling operations to install cables and instruments. They are interested in help in identifying equipment that could do this job, which requires drilling holes over a long distance in a semi-automatic mode. They considered using waterjet cutters, but due to criticality concerns, using water in the Shelter is strictly controlled and is not considered feasible.

2.2.3 Shelter Access and Debris Removal

As a result of the accident and subsequent construction activities to build the Shelter, access to the facility is severely limited. Providing access to areas is a very important consideration and limitation on the deployment of remote systems in the Shelter. Normal access corridors have been obstructed by the collapse of building structures, debris expelled by the reactor explosion, and fuel masses that have flowed in a lava-like manner into areas below the reactor vessel. In addition to the access problems caused by the accident, additional obstructions have been caused by concrete that was poured during Shelter construction and flowed in an unrestrained manner into a number of areas. To implement the work planned for characterization, stabilization, and remediation, this debris must be removed to provide access routes for personnel and equipment.

To date, debris removal is primarily a manual operation that is very slow and tedious with significant exposure to personnel (see Figure 2.5). Heavy robotic systems for major construction have been

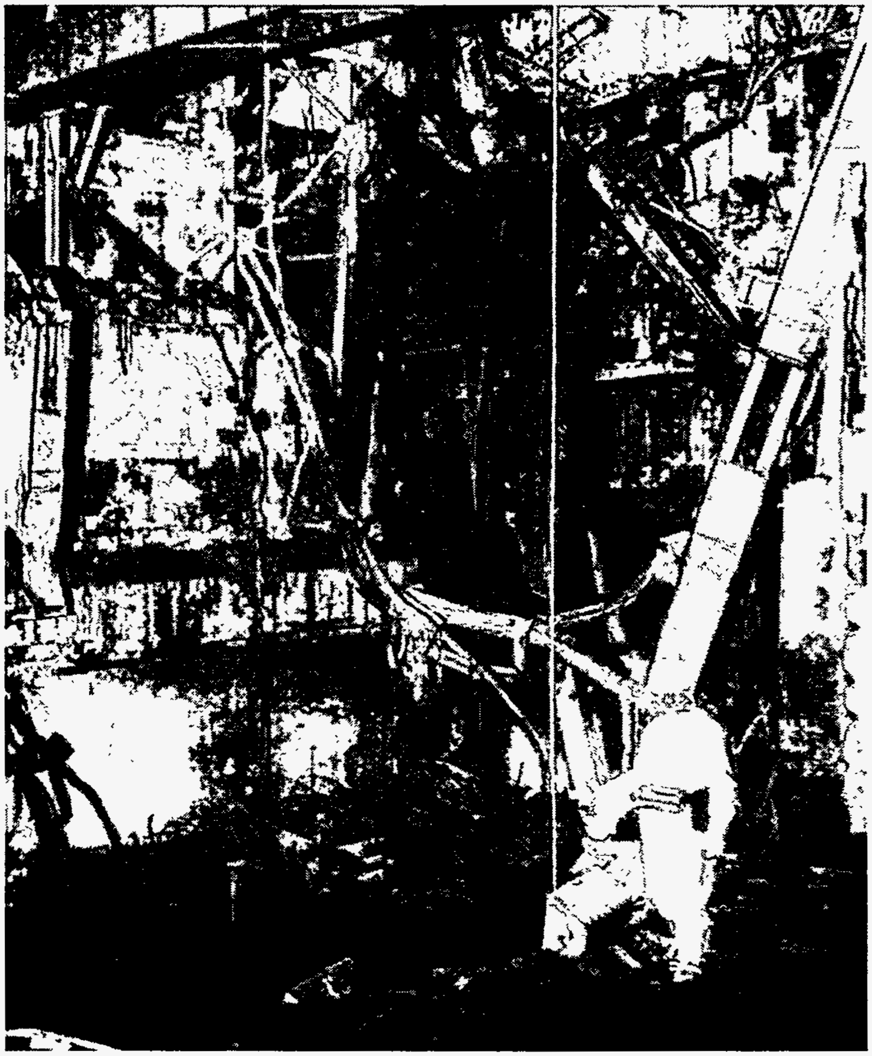

Figure 2.5. Debris from Explosion Blocking Access

evaluated by Shelter Operations but are currently considered not practical due to access constraints and the expected high cost of such systems. Before use of heavy robotic equipment is considered, planning for these systems needs to be integrated into the operational planning and funding profiles for Shelter Operations.

Many debris removal tasks are likely operations for remote systems: moving, collecting, and packaging loose debris; cutting structural materials; drilling or breaking up concrete or fuel materials; placing shielding to create protected corridors or work areas, and decontaminating areas with loose contamination. Remote platforms for clearing debris and breaking up obstructions to provide access for operations will be needed. Technical schemes for providing access to the Shelter are being developed by the Shelter Operations organization in collaboration with the Atomenergoproekt Kiev. Plans include the installation of an elevator to transport personnel and equipment.

2.2.4 Fuel Containing Materials Investigations

There are three areas of the Shelter where there is great need for deployment of remote systems for diagnostic investigations. These are Room 305, the Steam Distribution Corridor (SDC), and the Central Reactor Hall. All three areas have high dose rates because they contain large amounts of FCM.

Room 305 is located below the reactor and is believed to contain a very large amount of FCM. This is an area of focus for criticality concerns and there is a need to perform both physical and chemical characterization of the FCM located in this room. To the north of this area is a large concrete layer that resulted from the construction of the Shelter, so access is very limited. Based on Shelter Operations experience, removal of concrete such as this will be too difficult for robotic systems. They have done limited investigations of this room and created a map of the fuel flow. A technical scheme defining the routes and loading limits has been worked out to reach this area. Adjacent rooms are being prepared for equipment staging, maintenance, and an operations center. Room 318 can be used for robot maintenance and Room 324 can be used as an operator control station.

Room 210, where steam is distributed during an accident release, is located directly beneath Room 305. The room houses a large number of heat exchangers connected by networks of pipes. The pipes run both horizontally and vertically through the room, making movement through the room very difficult. The FCM flowed from Room 305 through the steam distribution valves and into the Steam Distribution Corridor. From this room it flowed down to the lower levels through the pipes of the bubbler pool. The importance of the Steam Distribution Corridor for robotics applications lies in the similarity of the conditions in this room to those in other areas of the building for which operational missions can be anticipated. The temperature, humidity and neutron fields in this room are similar to the other mission-operational areas. The general tasks of interest in the Steam Separator Room are to survey the area to determine the location and quantities of FCM, to survey the floor and roof to determine their structural integrity, and to survey the walls and other structural elements for damage or degradation.

Work in the Central Hall is needed to perform inspections, clear access, and characterize both the fuel and structural conditions. Some sensors have been installed in this area, but work by personnel is very hazardous due to radiation levels and also industrial safety concerns. Other tasks in the Central Hall will involve diagnostics and other preparatory measures for structural stabilization work. Some radiation mapping in the central hall has been performed with a gamma camera, but the information is limited. Mr. Korneev would like to have an improved radiation mapping system and a better method to deploy a mapping system in the Central Hall. The physical geometry and access within this area is not well documented, as access to the area is so limited. Deployment of robotic systems will be challenging due to the unstructured environment. They have also had limited success in using a laser range camera to develop topographical maps of the central hall. Improved remote mapping capability is an area of interest and will help in providing data needed to plan future activities to be conducted in the Central Hall and other areas.

2.2.5 Buried Waste Removal

Following the accident, during construction of the Shelter, a significant amount of radioactive waste and expelled fuel was buried in place, covered either by the Shelter structures, such as the Cascade Wall, or by clean overburden soils that were brought in. The materials buried include contaminated debris from the accident and natural items such as stones. The contaminated debris includes wood, metals, concrete fragments, graphite, and fuel materials. Currently plans are being developed to establish a radioactive waste handling facility in the vicinity of the Shelter. This facility will be used to handle and package radioactive waste materials generated during the decontamination, decommissioning, and dismantlement of the nearby ChNPP reactor units 1, 2, and 3 and waste generated in the stabilization and remediation of the Shelter. It is the position of regulatory agencies in Ukraine that the buried waste materials at the proposed construction site of the waste management facility will need to be excavated and stored in a safe location. Currently this work is outside the scope of the INSP Chornobyl Shelter Initiatives and is the responsibility of the Westinghouse Project Management Unit that is working with the ERBD. However, to fully document information obtained during the needs assessment it is included in this report for reference.

To remove the buried waste that is not covered by the Shelter structures, the following types of operations would be performed. The buried waste would need to be located through remote sensing operations and a plan for its excavation developed. During excavation operations, dust suppression measures will need to be undertaken to prevent the dispersal of airborne contaminants. Following removal, waste items would be segregated by size and contamination levels to sort items to the appropriate decontamination and packaging operations. Dose levels in the areas in which this work is to be conducted are not well measured. There is a proposed plan to drill boreholes to measure the levels of contamination, but it is doubtful that these will give an accurate assessment of the conditions. The radiation levels in this area are uncertain, but it is believed that some relatively hot items, such as fuel, are buried here. Currently a French company has been involved in site assessments to locate buried waste at the ChNPP site. Data gathered to date has been of limited value. Currently there is no good method to distinguish between buried materials that are radioactive and those that are not. Identification of a technology that would enable this type of discrimination of buried materials is needed.

The buried radioactive waste will have to be dug up and packaged for safe disposal. This work needs to be done prior to construction of the waste handling facility to be located beside the Shelter. Currently this type of activity can only be done manually with the risk of significant dose uptake to workers. The Shelter staff would like assistance in evaluating the feasibility of proposed commercial equipment to perform the required work, including machines and remote sensors to locate, remove, segregate, and package the buried waste materials. The ISTC Shelter is conducting some research to identify remote sensors to locate buried waste using ground-penetrating radar. A significant amount of work has been done in the DOE Office of Environmental Management (EM) programs on buried waste and there is an opportunity to transfer information and experience from these programs to the Ukrainians to support this need. The need for these systems is short term, as the construction of the facility needs to happen soon to support work in decommissioning the other reactor units at Chornobyl.

2.2.6 Evaluation Assistance

Mr. Korneev is very interested in learning more about the remote systems capabilities of companies in the West who can provide commercial systems that can be adapted to meet the various needs for remote systems in the Shelter. There is a strong interest in applying commercially available technologies that are production models with a proven track record. This is likely to provide the most cost-effective and robust solutions to the Shelter's remote systems needs. Shelter Operations is approached by many commercial vendors and is interested in having assistance in evaluating the capabilities and potential of their systems to ensure that they can perform their advertised function. Mr. Korneev feels that the assistance of some third-party experts would be helpful in making sound technical and cost decisions in the remote technology area. Consideration should be given to establishing a supporting consulting board made up of independent remote systems experts, not affiliated with the commercial industry suppliers. This board could serve to provide advice on a consulting basis to support the Shelter Operations organization, the PMU, and the EBRD without potential conflict-of-interest situations arising.

3.0 Shelter Implementation Plan Evaluation

The INSP Chornobyl Shelter Initiatives are focused on activities defined under the *Chernobyl Unit 4 Shelter Implementation Plan* (Kessler and Kostenko 1997). This is a follow-on report to the *Chornobyl Unit 4 – Short and Long Term Measures – Final Report* (Tacis 1996) and provides a comprehensive plan to convert the Shelter to an environmentally safe site over a period of the next ten years. The Shelter Implementation Plan provides a detailed plan of action and cost estimate for implementation of the recommendations of the first study. Appendix C provides a summary of costs and schedules for these tasks as described in the Shelter Implementation Plan.

The work outlined in this plan will be organized into specific projects that will be funded through contributions of the G-7 nations (pledges), which will be managed through the EBRD. The G-7 nations voted to provide $300M funding to the EBRD to support the Chornobyl Shelter works at the June 1997 Summit meeting in Denver, Colorado (*Energy Daily* 1997). The EBRD will act as the contracting agency to disperse the funds through a project tendering process. Currently, it appears that plans are to address remote systems needs as part of the individual projects that are commissioned through the EBRD. There is no current plan for an independent remote systems technology program sponsored by the U.S. DOE under the INSP.

Although Task 20 is the only activity that explicitly relates to remote systems technologies, it is likely that remote systems will play a significant part in the implementation of most of these projects. The G-7 nations have agreed to invest in identifying and developing technologies for fuel removal. However, the G-7 nations have taken a firm stance that they will not provide funding for fuel removal at this time. The remote systems requirements associated with these tasks is described below in Section 3.2. Remote systems applications will crosscut the individual projects with similar requirements and systems needed to support multiple activities. Therefore, close coordination of work in this area is recommended to avoid duplication of effort and investments. Establishment of common facility interfaces, operator protocols, and maintenance considerations should be considered to streamline implementation and reduce costs for remote technology deployment.

3.1 Shelter Implementation Plan Summary of Tasks

The "Recommended Course of Action" defined short- and long-term measures for creating an environmentally safe condition at the Shelter. These measures were grouped according to five main objectives:

Task Group 1: reduce collapse probability (structural stabilization)

Task Group 2: reduce accident consequences

Task Group 3: improve nuclear safety

Task Group 4: improve worker and environmental safety

Task Group 5: long-term strategy and study for conversion to an environmentally safe site.

The Shelter Implementation Plan takes the phases and measures defined in the Short- and Long-Term Measures report and develops them into an integrated plan organized into 22 tasks. Descriptions, cost estimates, schedules, and analysis of early biddable projects for each of these tasks are presented in the plan.

The Shelter Implementation Plan provides a detailed work breakdown structure, organized around the 22 tasks, which form the foundation for the task analyses, cost estimates, and schedules. Major milestones and key decision points are provided and included in the project schedule. Three major programmatic milestones are identified in the report as key decision points:

1. Stabilization and shielding strategy decision, which forms the basis for defining the feasibility of the currently proposed structural stabilization actions and includes consideration of the need to provide access and worker protection (8/31/98)

2. Fuel-containing material (FCM) removal strategy decision, which defines the methods and best time frame for FCM removal based on results of feasibility and cost-benefit analyses (6/28/01)

3. Confinement strategy decision, which will determine the design and functions required based on a conceptual design for a new confinement structure that is consistent with the stabilization and FCM removal strategies. (12/8/99)

The 22 tasks are divided among the five task groups listed above as follows:

Reduction of accidental collapse potential (Tasks 1-8)

Task 1: Stabilization and Shielding Design Integration and Mobilization

Task 2: Stabilization and Shielding of Western Section

Task 3: Stabilization and Shielding of Mammoth Beam and Southern Section

Task 4: Stabilization and Shielding of Eastern and Northern Section

Task 5: Stabilization of Roof, Roof Supports, and Covering

Task 6: Structural Investigation and Monitoring

Task 7: Geotechnical Investigation

Task 8: Seismic Characterization and Monitoring

Reduce Collapse Accident Consequences (Tasks 9-11)

Task 9: Emergency Preparedness

Task 10: Dust Management

Task 11: Emergency Dust Suppression System

Increase Nuclear Safety (Tasks 12-14)

Task 12: Criticality Control and Nuclear Safety

Task 13: Contained Water Management

Task 14: Fuel Containing Material (FCM) Characterization

Increase Worker and Environmental Safety (Tasks 15-18)

Task 15: Radiological Protection Program

Task 16: Industrial Safety, Fire Protection, Infrastructure and Access Control

Task 17: Integrated Monitoring System

Task 18: Integrated Database (Configuration Management)

Long Term Strategy and Study for Conversion to an Environmentally Safe Site (Tasks 19-22)

Task 19: FCM Removal and Waste Management Strategy and Study

Task 20: FCM Removal Technology Development

Task 21: Safe Confinement Strategy

Task 22: Implementation of a Safe Confinement to Support Deconstruction and FCM Removal.

3.2 Shelter Implementation Plan Task Descriptions and Needs

Below each of the Shelter Implementation Plan tasks is evaluated to identify areas where remote operations may be applied to reduce exposure to personnel or enable work in areas where radiation levels preclude human entry. Equipment and systems requirements to perform these remote operations are further discussed in Section 4.0 below. The following descriptions of tasks are abstracted from the Shelter Implementation Plan. Although the need for remote operations is mentioned in several places in the Shelter Implementation Plan, specifics on the remote tasks and functional requirements are not discussed. Therefore, the discussion below is based on preliminary evaluation of the task descriptions and discussions with representatives of the technical team that worked on development of the Shelter Implementation Plan.[a]

Structural Stabilization Task Group (Tasks 1 – 8)

Task 1: Stabilization and Shielding Design Integration and Mobilization

This task covers conceptual design and analysis of all structural stabilization tasks combined as a single package of work. The scope of work covers implementation of general preparatory activities at ChNPP and Slavutych, as well as assessment of alternatives and conceptual designs for stabilization work described under subsequent tasks. This task establishes the design basis for these stabilization actions, including evaluation of existing structures and geotechnical designs. This task will also expedite review and analysis, leading to design confirmation for those measures that are mature in the Ukrainian design process. Lastly, this task mobilizes the preparatory work necessary to begin structural stabilization, including long lead procurements and infrastructure upgrades.

According to the Shelter Implementation Plan, work on this task is already underway by the Ukrainian Academy of Engineering Services, NIISK, and is planned for completion in mid FY 1997. There are no specific references to remote systems being part of this work. This effort will establish the baseline for international tendering for the individual group tasks in late FY 1997. Mobile remote platforms with manipulative capabilities for debris removal, installation of services, and diagnostic work will be required to support the preparatory work for Tasks 2 through 5.

(a) Discussions were held with Edward Warman of Stone and Webster Engineering Co., Ken Jackson of Bechtel Hanford Inc., and Jean Raymond Costes of CEA France, who all contributed to development of the Shelter Implementation Plan.

Task 1 Remote Systems Needs:

As part of the preparatory work for conducting stabilization activities and upgrading the facility infrastructure, remote systems will likely be needed. The Shelter Implementation Plan does not provide detail on the specific tasks to be undertaken; however, evaluation of options and tradeoff studies on utilizing remote technologies are part of Task 1. Under Task 1 the role of remote systems will be defined as a major part of the integrated design solution. Subsequent tasks will involve the development and utilization of remote equipment as called for in the integrated design.

Examples of applications for remote systems to be determined under Task 1 are clearing of debris for access and installation of shielding and services, such as lighting and electrical conduits, may be required. The application of mobile remote systems to support surveys of radiation levels, clearing of debris, installation of equipment and services may be required in areas of high dose. Use of remote equipment to perform decontamination and installation of shielding could also be required. The pre-conceptual design for implementation of the stabilization efforts performed under Task 1 should define the specific stabilization operations requiring remote equipment and define functional requirements for specific system applications. A centralized effort to coordinate planning and implementation of remote systems for stabilization will be beneficial for several reasons. First, the stabilization tasks are likely to have similar remote technology needs. Coordinated planning and investment could ultimately reduce costs by providing systems that could be deployed and operated by a trained staff to support multiple projects. Coordinated planning of remote technology applications should address consideration of commonality in operational interfaces, Shelter infrastructure interfaces, and support systems (e.g. power generators, hydraulic power units, or decontamination stations) and tooling.

Task 2: Stabilization and Shielding of Western Section

The objective of this task is to reduce the risk of structural failure of the western wall, west buttress wall, and adjacent framing. Load bearing girders B1 and B2 rest on this structure and are the principal supporting members for the main portion of the Shelter roof. This task covers the detailed design and implementation of the stabilization measures defined in Task 1, as they specifically relate to these structures. There is a significant issue with dose reduction and a desire to implement ALARA methodologies to reduce dose uptakes that are predicted to be too high for manual operations. Three major work elements include (note these elements apply to Tasks 3 – 5 also):

- Scientific investigations of the structural stabilization design
- Addressing the interaction of activities with other zones of the Shelter
- Design of structural stabilization measures.

Task 2 is a successor to activities defined in Task 1 and will not be fully implemented until completion of the Stabilization Decision Confirmation milestone is completed. Until this milestone is complete, activities under Task 2 will be limited to review and documentation of ChNPP work. Detailed design is scheduled to proceed beginning in late 1998, with construction beginning in 1999 and complete in 2001.

Task 2 Remote Systems Needs:

Design of the stabilization measures will require the definition of preparatory work and installation methods, which will likely require the application of remote methods or a combination of remote and manual operations to reduce personnel exposure. Remote operations may include removal of debris and obstructions to clear access, transport of materials, and installation of structural stabilization members. Planning for remote equipment should be undertaken as part of the early reviews conducted under this task. This will allow time to identify appropriate technologies and systems requirements. Remote systems such as mobile platforms with manipulative capability for diagnostics and larger systems for emplacement of structural supports will be required. Mobile remote platforms with manipulative capabilities for debris removed, installation of services, and diagnostic work will be required to support the preparatory work for Tests 2 through 5. Specific requirements for remote systems to support structural installations will need to be more clearly defined as the design for structural stabilization is better defined.

Task 3: Stabilization and Shielding of Mammoth Beam and Southern Section

The objective of this task is to reduce the probability of substantial displacement or collapse of the mammoth beam and its support, the deaerator block, and adjoining structures. The task will stabilize these structures against horizontal loads at the western end of the beam and southern part of the structure (turbine hall).

Detailed design for Task 3 will begin in the second quarter of 1998 with construction beginning late the same year and continuing until 2001.

Task 3 Remote Systems Needs:

The remote tasks are the same as for Task 2 above.

Task 4: Stabilization and Shielding of the Eastern and Northern Sections

The objective of this task is to reduce the probability of displacement or collapse of the ventilation chimney, the separation wall between Block "B" and the Shelter, and the northern section of the Shelter. Collapse of the chimney could damage Unit 3 and its service systems and potentially contribute to failure of the Unit 4 Shelter. Stabilization of the ventilation chimney is scheduled for completion in 1997. Detailed design of the remaining activities under this task is dependent on completion of the Stabilization Decision Confirmation milestone in 1998. Detailed design will be completed in late 1998 with construction completed by 2001.

Task 4 Remote Systems Needs:

The remote tasks are the same as for Task 2 above.

Task 5: Stabilization of the Roof, Roof Supports, and Covering

The objective of this task is to modify the roof structure of the Shelter to reduce collapse potential and improve confinement functions for the next 10 to 15 years. The required work involves implementing stabilization measures to reduce horizontal movement of the roof beams and plates and possibly installation of a new rigid roofing structure. Detailed design under this task is dependent on completion of the Stabilization Decision Confirmation milestone in 1998 and a subsequent milestone in 1999 for a decision on whether or not to proceed with roof stabilization measures.

Task 5 Remote Systems Needs:

The work required to stabilize the existing roof structure and construct a new rigid roof would most likely require working with a remote manipulation capability supported from a suspension device or support bridge over the roof structure. The ability to hold and manipulate suspended payloads for removal of existing structures and installation of new structures will require systems capable of lifting and manipulating much heavier payloads than diagnostic systems.

Task 6: Structural Investigation and Monitoring

The objective of this task is to develop a comprehensive monitoring program to provide data to support stabilization activities. This task includes the development of a digital model of the Shelter that will be used to support structural stabilization activities. This program will include investigations of different structural elements, including non-destructive testing and in-situ monitoring.

The structural investigations will begin in 1997 and a report on the findings will be issued in 1998. Monitoring systems will be designed in 1998 and installed by 1999.

Task 6 Remote Systems Needs:

Mobile remotely operated deployment platforms with improved travel capability to go across the debris and manipulative capability will be required to support the deployment and emplacement of sensors and monitoring devices to measure structural conditions. Remote inspection capabilities using visual and other non-destructive sensing capabilities will need to be deployed in areas of rugged terrain and limited access. Remote systems in the form of rugged mobile platforms with on-board manipulation capability and versatile tooling to perform installation and testing activities are likely to be required to support this task. Remotely deployed mapping technologies may be applied to gather electronic data that can be used in developing the digital models of various areas of the

Shelter. Some work in integrating data from mapping technologies with computer modeling systems has been done within DOE technology programs that might be applicable to this area. Technology is now available (e.g., frequency modulated [FM] laser range cameras) to begin to dimensionally map the high radiation areas of interest remotely. These metrology systems might also be useful to map longer-term structural movements if acceptable hard baseline points can be identified.

Task 7: Geotechnical Investigation

The objective of this task is to provide data on settlement and stability analysis of Unit 4 and surrounding buildings.

Task 7 Remote Systems Needs:

No remote tasks appear to be required to support this activity, unless observations or placement of sensors in high-radiation or physically dangerous locations are required.

Task 8: Seismic Characterization and Monitoring

The objective of this task is to provide data on seismic criteria and activity for use in support of other tasks.

Task 8 Remote Systems Needs:

Limited remote tasks appear to be required to support this activity, unless observations or placement of sensors in high-radiation or physically dangerous locations are required.

Collapse Accident Consequence Mitigation Group (Tasks 9 – 11)

Task 9: Emergency Preparedness

The objective of this task is to provide an emergency preparedness plan to minimize the impact of an event of Shelter collapse, criticality, fire, or other potentially hazardous events on the worker population. The plan will be started in 1997 and completed in 1998. The plan will be updated periodically to reflect any changes in the Shelter situation resulting from the short-term and long-term measures.

Task 9 Remote Systems Needs:

Systems to perform reconnaissance or rescue operations (e.g., locating and transporting personnel) in the event of an emergency situation should be planned for and available as part of the emergency response plan.

Task 10: Dust Management

The objective of this task is to protect workers and the environment from the effects of loose contamination in the Shelter through the use of fixatives or the application of decontamination techniques. The first activity to be performed is an investigation to quantify the amount of dust in locations throughout the Shelter and to determine its chemical and physical properties. A number of localized operations conducted as part of the Shelter Implementation Plan tasks will generate dust that will need to be controlled or prevented from becoming airborne. The control of airborne contaminants will be an important aspect of stabilization and remediation work.

Dust management activities will begin in 1997, including analysis of alternatives, development of procedures, and establishment of contamination control zones. These activities will be completed in 1998. The application of fixatives and other control activities will continue through 2002.

Task 10 Remote Systems Needs:

In areas of high radiation levels or other physical hazards, sampling and visual inspection to characterize the dust situation in the Shelter will need to be performed remotely. Remote deployment methods to apply local dust fixatives or collect and package dust materials may be needed prior to and during stabilization projects. If ventilation is installed in areas to control dust, remote handling and maintenance of contaminated filters may be required if dose levels are high.

Task 11: Emergency Dust Suppression System

The objective of this task is to design and install emergency dust suppression spray systems that would mitigate the dispersion of dust in the event of a structural collapse of the Shelter. These systems could also be used to mitigate the localized generation of dust from construction and demolition activities such as drilling, boring, and grinding activities.

The design of dust suppression measures is underway in Ukraine. Conceptual design, proof of principle testing, and detail design will be completed in 1998. Equipment will be procured and installed by 1999.

Task 11 Remote Systems Needs:

The installation of piping and pumps needed for the dust suppression system may require remote systems. The task specifically identifies remote technologies as needed to reduce worker exposure. This task will likely require vehicle systems capable of transporting and installation of heavier payloads than the diagnostic systems.

Improve Nuclear Safety Task Group (Tasks 12 – 14)

Task 12: Criticality Control and Nuclear Safety

The objective of this task is to effectively ensure that the FCM remains subcritical and eliminate the risk of radiological releases from a criticality event. The task involves installation of radiation detection (neutron monitoring) equipment near the FCMs to collect better data on the criticality potential and to support safety analyses. The task also will provide criticality guidance to support FCM removal strategy development. This task is currently underway as a U.S. bilateral project in cooperation with Shelter management. A prototype system will be tested and shipped from the United States in 1997; the prototype system will be retested, certified, and installed in the Shelter in 1998.

Task 12 Remote Systems Needs:

This task will require remote systems technologies to access locations containing FCMs to deploy sensors, and closely related to work under Task 14 to obtain quantitative data on FCM configurations and obtain samples to validate quantitative input data for criticality analysis. A versatile mobile platform with improved travel capability and manipulative capability to deploy various sensors will be required. This could be similar to the system applied for structural investigations.

Task 13: Contained Water Management

The objective of this task is to characterize the sources, amount, flow paths, and radiological properties of water contained within the Shelter. This task involves using existing data, as well as performing surveillance and sampling of known locations of water accumulation. It will also involve the design, installation, and testing of a water management system. Work on the task is underway at the Shelter with investigations and sample analysis being performed. A water management plan will be completed in 1997. Detail design of the water management system will be completed in 1998 and installed and tested by 1999.

Task 13 Remote Systems Needs:

This task will involve use of remote systems to obtain samples in areas of high radiation dose by drilling holes into areas not directly accessible using remotely operated or semi-automated equipment. A hot laboratory will be needed to upgrade very limited capabilities currently available at the ISTC "hot" laboratories in the town of Chornobyl. Remote handling equipment (e.g. manipulators) may or may not be required for this laboratory, depending on dose levels from samples. Currently analyses at the ISTC laboratory are contact handled.

Task 14: Fuel Containing Material (FCM) Characterization

The objective of this task is to precisely define the location of fuel and FCMs and understand its configuration and inventory to support criticality investigations. This task involves the evaluation, selection, development, and procurement of required systems to enable radiation and heat measurement studies and sampling activities to be performed in a variety of locations. This may include sampling or investigation of fuels encased under the Shelter walls or concrete flows created during construction. Samples will be analyzed in an on-site hot laboratory. This task will provide data to support analysis of risk-cost-benefit leading to a decision on removal of the fuel and FCMs from the Shelter. Characterization will proceed in two phases. Phase one is to obtain in-situ data from relatively easily accessible premises. Based on fuel balance calculations and analyses, a key decision on how much characterization is required will be made prior to initiating Phase 2, to conduct more comprehensive investigations of FCM deposits, including obtaining samples of material for analysis in a "hot" laboratory.

FCM characterization has been going on for years at the Shelter. This work needs to start as early as possible because of the importance of the nuclear safety questions that need to be resolved. In 1997 a characterization plan will be developed and activities will be started in 1998. Some work has already been initiated to develop sample and survey systems for early use.

Task 14 Remote Systems Needs:

Application of remote technologies to support the operations required to characterize FCMs is specifically identified as part of Task 14. During Phase 1 mobile remote diagnostic systems will be required to access areas of high dose and to remotely obtain in-situ data by direct radiation measurements, gamma and alpha radiation, heat and neutron flux measurements, and video imaging. Versatile reconnaissance platforms with the ability to deploy a variety of tools and sensors will be needed. In Phase 2 systems to obtain samples by coring, as well as the required support technologies for packaging, transport and analysis of the samples will be required. The Pioneer project, discussed in Section 5.5, is currently developing a system that will provide the capability to perform coring of structural materials. Adaptation of this type of technology to perform similar coring of samples from the FCMs could be applied to address this need. Hot analytical laboratories for sample handling and analysis will likely require application of remote technologies such as manipulators.

Improve Worker and Environmental Safety Task Group (Tasks 15 – 18)

Task 15: Radiological Protection Program

The objective of this task is to improve worker safety by monitoring and controlling surface contamination levels and airborne radioactivity levels and radiation exposures, and by ensuring that personnel are adequately trained and have the required personnel protective equipment.

Task 15 Remote Systems Needs:

Remote systems are needed to perform decontamination and dust suppression in areas of the Shelter with high radiation levels and aerosol activity, to establish safe passage, and to install shielding. The application of remote technologies to perform work in the Shelter will support efforts to reduce worker exposure, which is the goal of this task.

Task 16: Industrial Safety, Fire Protection, Infrastructure and Access Control

This task will provide for improvement of industrial safety and fire protection conditions in the Shelter. An industrial safety strategy will implement needed upgrades to the facility infrastructure in such areas as lighting, electrical power, fall protection, ventilation and exhaust filtration, fire detection and suppression, and improved personnel protective equipment. Measures will be implemented to control unauthorized access and control of personnel movement within the facility. A surveillance program to better identify deteriorating conditions and develop corrective actions will be implemented.

Because of the importance of this task to worker safety at the Shelter, work is already underway and will continue as an ongoing activity.

Task 16 Remote Systems Needs:

Remote systems could be used for remote surveillance capabilities to perform inspections in areas that are considered to be risky from an industrial of radiological safety perspective. Surveillance equipment covered under other tasks would likely provide the type of service required for this task. The same type of mobile diagnostic capabilities as defined above could support this requirement. Remote systems could also be used to emplace infrastructure. There will be a major need for remote technologies associated with access control. This is closely related to the requirements for installation of shielding described in Tasks 1 through 5.

Task 17: Integrated Monitoring System

This task provides an integrated monitoring system under a centralized control system. The monitoring system will include systems for nuclear safety, radiation monitoring, radioactive emissions, site meteorology, structural stability, fire protection, and physical security. The Shelter organization has implemented systems called "Finish" and "Shatyor"to collect monitoring data from installed sensor packages throughout the Shelter. The data from the Finish sensors is collected at the Shelter facility and electronically transmitted daily to the ISTC Shelter laboratory in the town of Chornobyl.

Task 17 Remote Systems Needs:

This task is primarily an electronic monitoring program while separate control and monitoring systems are to be established under Tasks 6, 9, 10, 11, 12, 13, 14, and 16, one can consider that no additional specific remote systems are required.

Task 18: Integrated Database

This task provides for the acquisition, compilation, and maintenance of relevant data associated with Shelter activities. This task will provide a comprehensive data management system and include a data management strategy. It is closely tied to Task 17 and provides the capability to identify emergency conditions and integrate emergency response measures.

Task 18 Remote Systems Needs:

No remote systems needs are identified to support this task.

Long-Term Strategy and Study for Conversion to an Environmentally Safe Site Tasks (Tasks 19 — 22)

Task 19: FCM Removal and Waste Management Strategy and Study

This task provides for development of a strategy for the removal, sorting, treatment, packaging, transporting, and disposal or storage of FCM and associated radioactive and hazardous materials. This will include assessment of feasibility, cost, and risk-related benefits for different options.

This task will begin in 1997 leading to a preliminary decision on FCM removal and waste management strategy in 1999. A conceptual study will be completed which will support a key decision milestone in 2001 on FCM removal and waste management strategy. Additional work will be outlined at that time depending on the outcome of the decision.

Task 19 Remote Systems Needs:

The development of such a strategy will include analysis of required remote systems to support both FCM removal and waste management activities. Evaluation of available technologies, as well as proof of principal demonstrations for new technologies, will be required and performed under Task 20 below. Technical evaluations of remote systems, including testing and proof of principle demonstrations will be required to support establishing feasibility and costs. If this work is to be performed in Ukraine, improvements to testing facilities will be required.

Task 20: FCM Removal Technology Development

The objective of this task is to support the development of the strategy described in Task 19 above. This task includes development and testing of technologies for removal, sorting, treatment, packaging, transporting, and disposal or storage of FCM and associated radioactive and hazardous materials. This task will also include techniques for establishing the fissile content and other properties of the FCM samples.

This task will begin in 1997 with evaluation of technologies. A decision milestone is scheduled for 1998 that will provide a decision on whether to proceed with FCM removal prototype testing. Detailed design and approval for the prototype test will be completed in 1999 with the testing and documentation completed by 2001. This activity should be coordinated with the planning for the FCM Characterization task.

***Task 20 Remote Systems Needs*:**

This task will directly involve the evaluation of remote systems technologies to support FCM removal and waste handling operations. The task will identify remote systems that are reliable and maintainable in high-radiation and contamination environments. Specific issues to be addressed include:

- Evaluation and selection of teleoperated platforms and other remote technologies, including the required tooling and end effector packages

- Evaluation and selection of waste packaging, transfer, sorting and classification technology

- Evaluation of remote operations related to dust control

- Evaluation of remote operations related to management of criticality.

The task should start with evaluation of adaptation of existing technologies and only conduct new research and development if a major technology gap is apparent. An important first step will be defining functional requirements for remote operations. These requirements then form the basis for technology evaluations and proof of principle testing. An evaluation of alternatives and cost-benefit analyses will be performed. Consideration of system requirements from other areas should be included to identify commonality of system designs where it is feasible and makes sense. Development of an overall strategy for remote technology implementation, including identification of factors such as infrastructure support and interfaces would be beneficial and would likely reduce costs.

Task 21: Safe Confinement Strategy

This task involves development of a strategy for long-term, safe, and reliable confinement. This measure would define the strategy for construction of a confinement structure to enable deconstruction of the Shelter roof. This structure would confine releases in the event of a collapse of the Shelter and those generated as a part of the deconstruction work.

This task will start in 1997 with completion of the conceptual design by 1999. A key decision milestone on the strategy is scheduled for 1999. Development of this strategy is closely linked to Task 1 (Structural Stabilization and Shielding) and Task 19 (FMC Removal and Waste Management Strategy) and pre-conceptual planning will occur simultaneously with those activities.

Task 21 Remote Systems Needs:

Consideration of remote technology requirements for conducting the deconstruction operations would be part of this strategy. Planning for remote systems would be undertaken as part of the conceptual design for the Safe Confinement and deconstruction actions. Large systems to perform dismantlement and removal of large structural components will be needed. Methods to package and reduce the size of items for disposal may be required. This area will need to be more clearly investigated as the plans for deconstruction are better defined. There may be the need to provide an integrated capability such as ground-based, mobile platforms with manipulative capability working together with overhead lifting and transport systems (remotely operated cranes) to perform this type of operation.

Task 22: Implementation of Safe Confinement Strategy to Support Deconstruction and FCM Removal

The objective of this task is to implement the strategy outlined in Task 21. The task will be implemented following the key Confinement Decision in 1999. Detailed design of the safe confinement structure will be completed in 2000 with construction scheduled for completion in 2004. Deconstruction work will be completed in 2005.

Task 22 Remote Systems Needs:

Remote systems requirements will be defined as part of the strategy developed under Task 21.

4.0 Composite of Remote Technology Analysis Needs at Chornobyl

Task requirement data have been obtained through two primary sources: 1) the Shelter Implementation Plan and 2) Shelter and ISTC staff.

The Shelter Implementation Plan has served as a fundamental source. This document was studied in detail to identify potential projects and tasks for remote operations. In some cases, the Shelter Implementation Plan specifically calls out activities that will involve remote technology. In other cases, it discusses projects where remote technology approaches should be considered as an alternative approach. The data obtained from the Shelter Implementation Plan are broad and general in nature.

The other primary source of data was discussions with Shelter Operations staff during our trip to Chornobyl in May 1997. The information obtained from these discussions is much more focused and detailed, but correlates with the Shelter Implementation Plan requirements as one would expect. These inputs also provide insight into the near-term operational priorities that exist at the Shelter. The buried waste removal task associated with the new waste handling facility is a requirement that did not show up in the Shelter Implementation Plan explicitly, but will certainly will need to be considered in the overall site remediation planning. Appendix B presents a composite table with a comparison of requirements from the Shelter Implementation Plan and the Shelter Operations staff.

This chapter provides a commonality analysis of the requirements obtained from the two somewhat independent sources. The purpose of this analysis is to eliminate redundancies to provide a single composite requirement list. The four tables in this chapter provide the following: 1) a list of general requirement classifications for remote tasks, 2) a matrix relating the task requirements identified by the two sources to the system requirements broken down by system class, 3) priorities for six identified system types, and 4) requirements for payload, mobility, etc., for these six generic system types.

4.1 Systems Requirements

Experience has shown that it is important to use the right types of parameters to characterize remote task requirements. Physical, functional, and performance-related parameters that "point to" remote system requirements drivers are essential. Requirement classifications used as guidelines in describing remote task requirements are listed in Table 4.1.

4.2 Remote System Equipment Classes

The remote task requirements identified in the Shelter Implementation Plan have been used to develop a corresponding set of remote system requirements that are presented here. System requirements have been approached in an integrated manner with the objective of identifying broad categories of needs. Broad remote needs categories have been codified by defining a set of remote system equipment classes. Three classes of remote systems have been identified.

Table 4.1. General Requirements Classifications for Remote Tasks

Requirement Classification	Examples of Related Parameters
Mobility, or transportation	Ingress/egress constraints: distance, terrain, obstacles, access size, floor loading allowables, power Environment: structured or unstructured, slopes and obstacles
Manipulation, or handling	Payloads, reach Degree of fine motion control required Access, obstacle sizes Precision, repeatability, degrees of freedom
Sensing	Viewing: lighting, view angles Radiation Thermal
Tooling	Cutting Welding Bolting/unbolting
Data communications	Distance Line of sight Tether pathway and obstructions
Human-Machine Interfaces	Control Data analysis and visualization

Class I. Class I remote systems are small systems that are agile and light with maximum payload capacities in the range of 10 to 100 kgs. These systems would be used primarily for diagnostic and inspection type missions within the Shelter. This class of machine will weigh in the range of 100 to 300 kgs. These systems may have special-purpose manipulators to take samples or position sensors. The Mobile Characterization System and the Andros robots discussed in Section 6.3 are examples of Class I systems.

Class II. Class II systems are medium-sized systems that are able to perform material handling and manipulation associated with work tasks like debris and shielding handling. These systems would have payload capacities in the range of 100 to 1,000 kgs and as a result will be much larger and more powerful than the Class I systems. These systems may incorporate dexterous manipulation capabilities to perform handling operations. In Section 6.3, the TSEE and ROSIE systems are examples of Class II machines.

Class III. Class III remote systems are the major machines that will be required to perform full-scale building structure and large-volume debris removal operations within the Shelter. These machines will be like construction equipment and will no doubt require payload capacities on the order of thousands of kgs. The TSEE on a larger scale is indicative of the type of machine that would exist in this category.

Class I and II remote systems are well-established technologies as evidenced in Section 6.3. Class III machines are not as well established. Some work has been done in the automation of standard earth moving equipment, but virtually no nuclear remote systems of this scale have been deployed.

4.3 Class/Requirements Matrix

System requirements are presented in Table 4.2 in a matrix form in which the robotic and remote system requirements (columns) of each of the three classes are defined in terms of the composite remote task requirements (rows). (A synopsis of this information was provided in Table S.1 in the summary of this report). This table defines which task requirements would be performed by which class of machines. This means that in most task areas, such as structural stabilization, the overall work will require multiple machines of the different classes deployed and working together as a unit to accomplish the objectives.

Table 4.2. System Requirements vs. Composite Task Requirements

Requirements from Shelter Implementation Plan and Shelter Operations		Equipment Class		
Task Area	**Composite Requirements[a]**	**Class I**	**Class II**	**Class III**
Structural Stabilization Task Group (Tasks 1-8)				
Task 1: Stabilization and Shielding Design Integration & Mobilization	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • radiation surveys • shielding decon	• mobility to/from work location • sensor platform for rad surveys • sensor platform for visual inspections • data capture	• mobility to/from work location • route preparation • push/handle debris • install and maneuver shielding • install services • decon shielding	Materials & Equipment Transport: • structural materials • shielding materials • debris handling and removal
Task 2: Western Section	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • structural inspection • materials transport • installation of structural stabilizers • radiation surveys • shielding decon	Same plus, • small coring • sensor installation	Materials & Equipment Transport: • smaller shielding materials • debris handling and removal Site Preparation: • debris clearing • drilling • access provisions • surface preparations Delivery Systems (Infrastructure): • utilities (electrical, lights, etc.) to support operations • lifting & rigging equipment Remote Construction: • install pipe, pumps, etc. Structural Repairs: • filling cracks • shoring weak areas	Materials & Equipment Transport: • structural materials • shielding materials • debris handling and removal Site Preparation: • debris clearing • drilling • access provisions • surface preparations Delivery Systems (Infrastructure): • concrete • structural members & components • lifting & rigging equipment Remote Construction: • install structures and supports • build forms, pour concrete • install pipe, pumps, etc.
Task 3: Mammoth Beam and Southern Section	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • structural inspection • materials transport • installation of structural stabilizers • radiation surveys • shielding decon • *Structural Investigations of B1, B2, and Mammoth.* • *transport and install sensors* • *visual inspection and nondestructive testing* • *position determination* • *store, retrieve, display data*	Same as Task 2	Same as Task 2	Same as Task 2

Table 4.2. (cont'd)

Requirements from Shelter Implementation Plan and Shelter Operations		Equipment Class		
Task Area	Composite Requirements[a]	Class I	Class II	Class III
Task 4: Eastern and Northern Sections	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • structural inspection • materials transport • installation of structural stabilizers • radiation surveys • shielding decon • *Short-Term Stabilization* • *reinforce ventilation stack*	Same as Task 2	Same as Task 2	Same as Task 2
Task 5: Roof, Roof Supports, and Covering	• on-roof radiation surveys • inspect existing structure • stabilize existing structure • construct/install new roof structure • high loads and long reaches • *Short-Term Stabilization* • *seal existing roof* • *on-roof radiation surveys* • *inspect existing structure* • *cutting and welding on roof*	Same as Task 2	Same as Task 2	Same as Task 2
Task 6: Structural Investigation & Monitoring	• transport and install sensors • visual inspection and nondestructive testing • position determination • store/retrieve/display data • *Structural Investigations)*	Same as Task 2	None	None
Task 7: Geotechnical Investigation	• NO REMOTE TASKS	N/A	N/A	N/A
Task 8: Seismic Characterization & Monitoring	• NO REMOTE TASKS	N/A	N/A	N/A
Collapse Accident Consequence Mitigation Group (Tasks 9-11)				
Task 9: Emergency Preparedness	• reconnaissance operations • rescue operations	• mobility to/from work location • sensor platform for rad and thermal surveys • sensor platform for visual inspections • transport emergency supplies • data capture	• mobility to/from work location • route preparation • push/handle debris • install and maneuver shielding • general mobile manipulation to perform rescue and assessment missions	None

Table 4.2. (cont'd)

Requirements from Shelter Implementation Plan and Shelter Operations		Equipment Class		
Task Area	Composite Requirements[a]	Class I	Class II	Class III
Task 10: Dust Management	• air sampling • visual inspections • local application of dust fixatives • collect and package dust material • filter changing, packaging, and transporting • *Dust Management* • *measurements to characterize flow paths* • *air sampling* • *visual inspections*	• mobility to/from work location • sensor platform for air sampling • sensor platform for visual inspections • sensor platform for air flow measurements • data capture	• mobility to/from work location • route preparation • push/handle debris • apply fixatives • install and replace filters	None
Task 11: Emergency Dust Suppression System	• installation of suppressant delivery equipment (i.e., pipes, pumps, etc.)	None	• install piping and flow distribution systems	None
Improve Nuclear Safety Task Group (Tasks 12-14)				
Task 12: Criticality Control & Nuclear Safety	• ingress/egress to FCM locations • install/deploy sensors • *Radiation Safety* • *install criticality monitors* • *access drilling/boring*	• mobility to/from work location • visual inspection • gamma camera imagery • radiation mapping • thermal mapping • data capture	Potential support functions: • clear access • debris removal • equipment staging • dust management and suppression	None
Task 13: Contained Water Management	• liquid sampling and transport • drill bore holes • ***measurements to characterize inlets, outlets, and flow paths***	• mobility to/from work location • sensor platform for water sampling • sensor platform for visual inspections • sensor platform for water flow measurements • data capture	• install piping and flow distribution systems • drill bore holes	None
Task 14: Fuel Containing Material (FCM) Characterization	• ingress/egress to FCM locations • measure alpha, gamma, and neutron radiation • visual imaging • core drill and sample • package and transport samples • *Fuel Investigations* • *sample and map FCMs in Room 305, Steam Distribution Corridor and the Central Reactor Hall* •	• visual inspection • physical sampling; small coring • gamma camera imagery • radiation mapping • thermal mapping • air sampling • data capture	Potential support functions: • clear access • debris removal • equipment staging • dust management/ suppression • physical sampling	None

Table 4.2. (cont'd)

Requirements from Shelter Implementation Plan and Shelter Operations		Equipment Class		
Task Area	**Composite Requirements[a]**	**Class I**	**Class II**	**Class III**
Improve Worker Safety Task Group (Tasks 15-18)				
Task 15: Radiological Protection Program	• NO REMOTE TASKS	None	None	None
Task 16: Industrial Safety, Fire Protection, Infrastructure and Access Control	• pre-operational safety inspections	None	None	None
Task 17: Integrated Monitoring System	• NO REMOTE TASKS	None	None	None
Task 18: Integrated Database	• NO REMOTE TASKS	None	None	None
Long-Term Strategy and Study for Conversion to an Environmentally Safe Site Tasks (Tasks 19-22)				
Task 19: FCM Removal and Waste Management Strategy and Study	See Task 20 • *Physical and radiological mapping of the Central Reactor Hall*	• map and monitor	None	None
Task 20: FCM Removal Technology Development	• ingress/egress to FCM locations • FCM mapping and analysis • FCM size reduction, special tooling • FCM and waste sorting, handling, packaging and transporting • monitor dust control and criticality	• map and monitor FCM processing • mobility to/from work location • visual inspection • physical sampling; small coring • gamma camera imagery • radiation mapping • thermal mapping • air sampling • data capture	• clear access • debris removal • equipment staging • dust management & suppression • operate sizing tools to break-up FCM • collect and package FCM pieces and material • transport FCM materials to storage locations • reconfiguration for criticality and thermal management	None

Table 4.2. (cont'd)

Requirements from Shelter Implementation Plan and Shelter Operations		Equipment Class		
Task Area	**Composite Requirements[a]**	**Class I**	**Class II**	**Class III**
Task 21: Safe Confinement Strategy	• large scale dismantlement • overhead and ground-mounted operations • *Buried Waste Removal* • *survey and map buried wastes* • *excavate and sort overburden* • *package contaminated soils*	• operational support reconn • visual inspection • physical sampling; small coring • gamma camera imagery • radiation mapping • thermal mapping • air sampling • data capture	Materials & Equipment Transport: • smaller shielding materials • debris handling and removal Site Preparation: • debris clearing • drilling • access provisions • surface preparations Delivery Systems (Infrastructure): • utilities (electrical, lights, etc.) to support operations • lifting & rigging equipment Remote Construction: • install pipe, pumps, etc.	Materials & Equipment Transport: • structural materials • shielding materials • debris handling and removal Site Preparation: • debris clearing • drilling • access provisions • surface preparations Delivery and Debris Removal Systems (Infrastructure): • concrete • structural members & components • lifting & rigging equipment Remote Deconstruction: • size reduction of steel and concrete items • sawing operations • jack hammers • install pipe, pumps, etc. • remotely operable backhoe and endloaders
Task 22: Implementation of Safe Confinement Strategy to Support Deconstruction and FCM Removal	See Tasks 20,21	Same as 20, 21	Same as 20, 21	Same as 20,21

(a) Shelter Operations Requirements are shown in italics.

4.4 Deployment Priorities

So far, the requirements shown in Table 4.2 do not define deployment priorities. Deployment priorities ultimately set corresponding development priorities for the remote systems that will be used at the Shelter. Reviewing the requirements identified in the Shelter Implementation Plan will enable prioritization. The previous study group, which developed the first report on short- and long-term measures, defined a recommended courses of action comprised of three phases related to the stabilization and conversion of the Shelter to an environmentally safe site. The G-7 Nuclear Safety Working Group and the Ukranians agreed in principle to proceed to implement Phases 1 and 2 as outlined in the Recommended Short and Long-Term Measures report. This agreement led to formation of a second study group that developed the Shelter Implementation Plan. Appendix 5 of the Shelter Implementation Plan contains further detail about these three phases and is summarized below. Table 3.2 of the Shelter Implementation Plan provides a correlation between Shelter Implementation

Plan tasks, work breakdown structure, and recommended actions phases/tasks from the original Short and Long-term Measures report. The relationship between Shelter Implementation Plan tasks and the phases of the recommended course of action from the short and long-term measures report (TACIS 1996) is shown below. This phase structure and task definitions can be used to assist in establishing near-term priorities and longer-term considerations with regard to robotic and remote systems developments and deployment.

Phase 1: Stabilization and other Short-Term Measures

Task 1.1 Reduce collapse accident probability by structural stabilization.

(Shelter Implementation Plan Tasks 1-8)

Task 1.2 Reduce accident collapse consequences.

(Shelter Implementation Plan Tasks 9-11)

Task 1.3 Increase nuclear safety by criticality control, contained-water management, and fuel containing material characterization.

(Tasks 12-14)

Task 1.4 Increase worker, industrial, and environmental safety.

(Tasks 15-18)

Phase 2: Preparation for Conversion to an Environmentally Safe Site

Task 2.1 Provide shielding and dust fixation for worker safety.

(Tasks 1 & 10)

Task 2.2 Design and construct a cost effective optimized new confinement.

(Task 21-22)

Task 2.3 Identify the appropriate fissile inventory removal technique and timing.

(Tasks 19-20)

Phase 3: Conversion Into an Environmentally Safe Site.

Task 3.1 Convert Shelter to a safe structure by utilizing the principles of either an earth shelter, or monolith shelter, or a combination of both.

(Task 22).

Task 3.2 Control and maintain the safe structure until a decision to remove is taken.

(Task 21 – Strategy only)

Task 3.3 Remove the fissile inventory if appropriate and necessary.

(Task 19 – Strategy only)

Robotic and remote systems are usually implemented in ways that allow the systems to perform a wide range of functions. To a great extent, such machines are general purpose. This generality is an important and valuable attribute in that they can be used to perform new tasks that were not originally anticipated. This case occurs often in unstructured work environments typical in nuclear applications. Based on experience and through analysis, the remote systems requirements given in Table 4.2 can be used to define generic systems that crosscut the multitude of functions identified (somewhat like another dimension to the table). For example, it is clear that there is a general need for a small sensor platform that can meet the inspection and monitoring needs of several task areas. If a single mobility platform could be developed to meet all of these requirements, this would of course be the most efficient and cost-effective path to follow. Care must be taken to focus on the most cost-effective approach, which may not in all cases point to the use of general-purpose, multi-application systems. Clearly established functional requirements will aid in developing the best approach and selecting appropriate technologies.

The preliminary analysis suggests that the requirements point to several different types of generic remote systems that can perform basic Shelter missions. These systems include

- inspection and diagnostic systems in which a mobile platform acts as sensor delivery system
- debris management systems in which a mobile robot work system has the ability to move, handle, and redistribute Shelter debris to clear access and work areas
- material handling systems that provide support in material delivery and removal from work sites
- deconstruction systems that have the ability to demolish and remove equipment and structures from within the Shelter areas
- construction systems that have the capabilities to reinforce existing structures and to install new auxiliary structures necessary to stabilize the Shelter
- excavation systems that allow major digging operations to be accomplished remotely.

The application of these six types of remote systems to the task areas defined in the Shelter Implementation Plan was studied relative to their importance in terms of priority and the likely timetable for their use. This analysis is summarized in Table 4.3.

Table 4.3. Systems and Priorities

(Implied) Generic Remote Systems	Inspection and Monitoring Systems	Debris Management System	Material Handling System	Deconstruction System	Construction System	Excavation System
Phase 1: Stabilization and other Short-Term Measures						
Task 1.1	Hi Priority[(a)] Near-term[(b)] Need	Hi Priority Near-term Need - access	Hi Priority Mid-term Need	Lo Priority Long-term Need	Hi Priority Mid-term Need	Not Applicable (N/A)
Task 1.2	Hi Priority Near-term Need - airflow	Medium Priority Near-term Need	Medium Priority Near-term Need	Lo Priority Long-term Need	N/A	N/A
Task 1.3	Hi Priority Near-term Need	Hi Priority Near-term Need - access	Medium Priority Near-term Need	N/A	N/A	N/A
Task 1.4	N/A	N/A	N/A	N/A	N/A	N/A
Phase 2: Preparation for Conversion into an Environmentally Safe Site						
Task 2.1	Medium Priority Near-term Need	N/A	N/A	N/A	N/A	N/A
Task 2.2	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	N/A
Task 2.3	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	N/A	N/A
Phase 3: Conversion into an Environmentally Safe Site						
Task 3.1	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need	Low Priority Long-term Need
Task 3.2	N/A	N/A	N/A	N/A	N/A	N/A
Task 3.3	N/A	N/A	N/A	N/A	N/A	N/A

(a) Priority is a measure of the significance of the system function to the condition of the shelter.
(b) Timeframe is a measure of how soon such systems might be deployed.

Generally speaking, priority in terms of task activities decreases from the top to the bottom of Table 4.3 while time frame increases. Phase 1 is essential while Phases 2 and 3 remain subject to debate and negotiations with tradeoffs between risk and funding. This table shows that there is a clear need for systems involving Class I and II machines that perform inspection, monitoring, debris and materials handling. Systems that can perform complex deconstruction and construction tasks within the shelter while assuring structural integrity are certainly more speculative in terms of technical feasibility and cost effectiveness. Cost-effective excavation systems are easily attainable. This analysis does define a clear and near-term need for remote inspection and monitoring systems, debris management systems, and material handling systems. The debris management and material handling systems play a support role for the inspection and monitoring systems.

4.5 Versatility of Generic Remote Systems

These general types of systems have been further studied in broad terms regarding their fundamental remote technology characteristics. Table 4.4 presents the fundamental requirements for mobility, manipulation, tooling, and sensing for these six generic systems and which classes they reside within. The table contains proposed numbers for parameters such as payload and reach. These quantitative requirements are purely estimates based on judgement and the data obtained to date. The purpose of these estimates is to roughly bound the sizes of the systems that are needed. The numbers presented are intended to provide bounds and limits on key system parameters.

Table 4.4 depicts a finding that was anticipated from the beginning of this needs assessment. The work systems needed to perform the wide ranges of tasks associated with stabilizing the Shelter should be realized by combining modular and re-configurable building blocks of basic robotics/remote systems technology, rather than constructing special machines for each job. The use of generic, versatile remote systems will reduce costs and risks, and simplify the implementation of these systems in the field. For example, the Class I mobile platform should be developed as a re-configurable system in which the propulsion scheme can be configured for mission-specific activities in a particular area of the Shelter to be surveyed. Tracked propulsion slows vehicle operations and should only be used where necessary. Wheeled propulsion is efficient and faster but is limited in terms of the sizes of obstacles and characteristics of terrain that can be traversed. The platform should be designed and developed such that tracks or wheels can be used or interchanged within the overall design. We are not proposing the development of general purpose, do-all machines but rather careful engineering analysis of overlapping requirements such that common subsystems can be built for multiple system applications. It is believed that this fundamental principle can be applied comprehensively across all of the systems needed at the Shelter. Alternatives to vehicle deployment could include crane- or gantry-deployed systems.

More specifically, this analysis states that the initial EBRD tenders should focus on mobility, manipulation, and sensing requirements shown for the inspection and monitoring, debris management, and material handling systems. As far as practical, generic subsystems (i.e. manipulators, sensors, etc.) that satisfy these requirements should be developed. These systems should be realized by combining and integrating the necessary mixtures from the generic subsystems.

Table 4.4. Generic Remote System Requirements

Generic Remote Systems	Class I - Light	Class II - Medium	Class III - Large
Inspection and Monitoring System	**Transport and take measurements**	**Clear assess to required areas**	
Mobility	• Payload: up to 100 kg Vertical obstacles: ≤20 cm • Ground clearance: ≤15 cm • wheeled propulsion for flat areas • tracks or articulated wheel drives for areas with climbing and higher obstacles • battery powered	• Payload: up to 500 kg • Vertical obstacles: ≤30 cm • Ground clearance: ≤15 cm • tracked vehicle which could clear access for the Class I system.	
Manipulation	• DOF: 3-5 min. • Reach: ~0.5 m • Payload: up to 5 kg • Actuation: electric • simple position controlled manipulator system to pick up samples and to do drilling operations. • communications repeater placement	• DOF: 3-5 min. • Reach: ~2 m • Payload: up to 200 kg • Actuation: hydraulic or electric • simple backhoe-like teleoperated manipulator which could be used to move large debris objects.	
Tooling & Sensing	• sensor suite: radiation, humidity, temperature, visible and infrared vision	• push blade • bucket • grapple • concrete jack hammer	
Debris Management System		**Provide ingress/egress pathways; manage and control radiation exposures**	
Mobility		• Payload: up to 500 kg • Vertical obstacles: ≤30 cm • Ground clearance: ≤15 cm • tracked vehicle to clear access for the Class I system.	
Manipulation		• DOF: 3-5 min. • Reach: ~2 m • Payload: up to 200 kg • Actuation: hydraulic or electric • simple backhoe-like teleoperated manipulator to move large debris objects.	
Tooling & Sensing		• radiation and thermography to scan for hot spots. • push blade • bucket • grapple • concrete jack hammer	

Table 4.4. (cont'd)

Generic Remote Systems	Class I - Light	Class II - Medium	Class III - Large
Material Handling System	**Provide auxiliary remote viewing**	**Handles medium-scaled objects for delivery of new materials and removal of material to be discarded**	**Handles large-scale objects for delivery of new materials and removal of material to be discarded**
Mobility	• Payload: up to 100 kg • Vertical obstacles: ≤20 cm • Ground clearance: ≤15 cm • wheeled propulsion for flat areas • tracks or articulated wheel drives for areas with climbing and higher obstacles • battery powered • serves as a stand-off remote viewing system	• Payload: up to 800 kg • Vertical obstacles: ≤30 cm • Ground clearance: ≤15 cm • Tracked, or articulated wheel, propulsion.	• Payload: up to 1500 kg • Vertical obstacles: ≤1 m • Ground clearance: ≤30 cm • Tracked, or articulated wheel, propulsion.
Manipulation		• DOF: 6-7 min. • Reach: 1-2 m • Payload: up to 200 kg • Actuation: hydraulic	• DOF: 3-5 min. • Reach: 3-5 m • Payload: up to 500 kg • Actuation: hydraulic
Tooling & Sensing	• remote viewing cameras with pan/tilt aiming.	• parallel jaw gripper • grapple • auxiliary lift ~1000 kg hoist	• parallel jaw gripper • grapple • auxiliary lift ~1000 kg hoist
Deconstruction System	**Provide auxiliary remote viewing**	**Perform more precise operations with medium-sized equipment items**	**Demolish and remove existing large-scale equipment and structures items**
Mobility	• Payload: up to 100 kg • Vertical obstacles: ≤20 cm • Ground clearance: ≤15 cm • wheeled propulsion for flat areas • tracks or articulated wheel drives for areas with climbing and higher obstacles • battery powered • serves as a stand-off remote viewing system	• Payload: up to 800 kg • Vertical obstacles: ≤30 cm • Ground clearance: ≤15 cm • Tracked, or articulated wheel, propulsion.	• Payload: up to 1500 kg • Vertical obstacles: ≤1 m • Ground clearance: ≤30 cm • Tracked, or articulated wheel, propulsion.
Manipulation		• DOF: 6-7 min. • Reach: 1-2 m • Payload: up to 200 kg • Actuation: hydraulic	• DOF: 3-5 min. • Reach: 3-5 m • Payload: up to 500 kg • Actuation: hydraulic
Tooling & Sensing	• remote viewing cameras with pan/tilt aiming.	• parallel jaw gripper • grapple • auxiliary lift ~1000 kg hoist	• parallel jaw gripper • grapple • auxiliary lift ~1000 kg hoist

Table 4.4. (cont'd)

Generic Remote Systems	Class I - Light	Class II - Medium	Class III - Large
Construction Systems	**Provide auxiliary remote viewing**	**Perform more precise operations with medium-sized equipment items**	**Stabilize existing structures by removing and installing large-scale structural members**
Mobility	• Payload: up to 100 kg • Vertical obstacles: ≤20 cm • Ground clearance: ≤15 cm • wheeled propulsion for flat areas • tracks or articulated wheel drives for areas with climbing and higher obstacles • battery powered • serves as a stand-off remote viewing system	• Payload: up to 800 kg • Vertical obstacles: ≤30 cm • Ground clearance: ≤15 cm • Tracked, or articulated wheel, propulsion.	• Payload: up to 1500 kg • Vertical obstacles: ≤1 m • Ground clearance: ≤30 cm • Tracked, or articulated wheel, propulsion.
Manipulation		• DOF: 6-7 min. • Reach: 1-2 m • Payload: up to 200 kg • Actuation: hydraulic	• DOF: 3-5 min. • Reach: 3-5 m • Payload: up to 500 kg • Actuation: hydraulic
Tooling & Sensing	• remote viewing cameras with pan/tilt aiming. • extendable vertical tower	• parallel jaw gripper • grapple • auxiliary lift ~1000 kg hoist	• parallel jaw gripper • grapple • auxiliary lift ~1000 kg hoist
Excavation System	**Provide auxiliary remote viewing and sensing**		**remove and sort earthen overburden in and around the Shelter**
Mobility	• Payload: up to 100 kg • Vertical obstacles: ≤20 cm • Ground clearance: ≤15 cm • wheeled propulsion for flat areas • tracks or articulated wheel drives for areas with climbing and higher obstacles • battery powered • serves as a stand-off remote viewing system		• Payload: up to 2000 kg • Vertical obstacles: ≤0.5 m • Ground clearance: ≤30 cm • Construction machines adapted for remote operations such as end loaders, backhoes, etc.
Manipulation			• DOF: 3-5 min. • Reach: 5-10 m • Payload: up to 2000 kg • Actuation: hydraulic
Tooling & Sensing	• remote viewing cameras with pan/tilt aiming. • extendable vertical tower		• radiation and thermography to scan for hot spots. • push blade • bucket • grapple

Table 4.4. (cont'd)

Generic Remote Systems	Class I - Light	Class II - Medium	Class III - Large
Remote Equipment Maintenance and Repair System	**Provide auxiliary remote viewing**	**Support operations and maintenance of remote systems; dexterous maintenance tasks involving non-contact disassembly/assembly**	
Mobility	• Probably none; systems requiring non-contact maintenance would be transported to the special maintenance area.	• Probably none; systems requiring non-contact maintenance would be transported to the special maintenance area.	
Manipulation	• DOF: 6-7 min., high dexterity • Reach: 1-1.5 m • Payload: up to 15 kg • Actuation: electric	• DOF: 3-5 min., low dexterity support to light manipulators • Reach: 1-2 m • Payload: up to 100 kg • Actuation: electric	
Tooling & Sensing	• remote viewing cameras with pan/tilt aiming. • standard parallel jaw grippers • special tools as required.	• standard parallel jaw grippers • special tools as required	

5.0 Remote Systems Technology Deployment

The Chornobyl Unit 4 Shelter represents a unique environment with very complex operational challenges. Remote systems have been used in limited ways up to this point. It is clear from discussions with Shelter Operations and review of the Shelter Implementation Plan document that a more comprehensive program for deployment of remote systems technology must be a central part of the Shelter remediation efforts. Deployment of remote systems must be accomplished in a very deliberate manner that meshes well with the people, the culture, and the general environment. Care must be taken to structure the deployment objectives in a manner that is consistent with Shelter Operations practices and level of knowledge of the staff that will be involved in the deployment operations. In the development of this assessment, several aspects of deployment that have clear bearing on success became apparent.

5.1 Deployment Approach

Mr. Korneev repeatedly emphasized the importance of deploying remote systems in a stepwise fashion. Stepwise deployment means starting out on a limited scale, involving a few systems in projects that have a high likelihood of success. Stepwise deployment is necessary to build confidence, gain experience, and incorporate lessons learned. Successes with individual systems will provide the foundation for the deployment of new systems that address more challenging tasks and operations. This approach is wise in that it will allow time to build supporting infrastructure and to allow the Shelter operating staff to develop confidence in remote operations. A key element of stepwise deployment is creation of proper facilities for testing and training. The supporting facilities infrastructure is critical to initiating and sustaining effective remote operations. Resources for this support infrastructure must be allocated from the beginning.

Preparations for deployment begin at the design stage. The suppliers of the remote technology must work closely with Shelter Operations staff throughout the design process. Shelter Operations must be involved in establishing the system requirement definitions, design reviews, and mission pre-planning. Specific attention needs to be given to the challenges of the Shelter environment when developing requirements and design criteria to address areas such as radiation hardening, tether management, system decontamination and maintainability, and component modularity. This not only ensures that the systems will meet practical deployment requirements, but it also fosters a sense of ownership that will be an important factor in any successful deployment activity. Computer-based graphical modeling simulation tools should be used in design development, as well as to support planning and analysis of specific missions.

Mr. Korneev is working with the regulatory agencies to define the required documents and approvals for activities that need to be performed in the Shelter. As discussed before, the current body of regulatory documents and requirements were developed for operating facilities. The situation and conditions at the Shelter are quite different, so a new set of special regulatory considerations must be developed. There has been little progress in this area to date; however, ChNPP staff are working with the Nuclear Regulatory Agency of Ukraine to develop regulatory guidelines that will enable practical implementation of work in the Shelter. They have currently received approvals to deploy drilling machines and hope to expand this to cover other activities. He is working on getting the required authorizations to deploy robotics to conduct video inspection and characterization activities.

5.2 Cost/Benefit Perspectives

There is no question that remote technology can be deployed in a reliable manner that reduces worker radiation exposure in a wide range of tasks. In the perspective of the Shelter operating staff, the cost of such systems will likely be considered high. It is unlikely that they would consider such systems cost effective in the absence of pressure to reduce dose uptake. When the radiation levels of a specific application are extremely high, remote operations are considered imperative; therefore, the higher expense of systems capable of withstanding those conditions is justified. When the radiation levels are lower, contact operations are more likely to be viewed as an alternative to fully remote operations. The radiation exposure standards used at the Shelter will have great bearing on which applications are considered.

Cost/benefit analysis is routinely performed at DOE facilities and in the commercial nuclear industry; however, the values used for estimated cost for radiation dose vary widely, particularly between government and commercial operations. One example of this formula is as follows[a]:

$$B = V - (P+X+Y)$$

where: B = net benefit from the introduction of the practice
V = gross benefit (savings generated)
P = production costs, excluding radiation costs
X = cost of radiation protection measures
Y = cost of detrimental level of radiation (cost of person-rem).

Values assigned for "Y" or person-rem can vary not only between facilities, but based on the level of radiation exposure. Current values used at PNNL[a] are $2,000/person-rem for activities expected to be less than 1 rem/year, and $10,000/person-rem for activities expected to exceed 1 rem/year. The current value used at the Idaho National Engineering and Environmental Laboratory is $6,500/person-rem. Generally, values used for U.S. government operations are more conservative than commercial nuclear plants, leading to the easier justification of implementing protective measures. Values assigned for person-rem at Ukrainian facilities were not available from the information reviewed for this report. This is an area in which the NRA will likely be involved in establishing guidelines for the ChNPP, including the Shelter.

(a) These values are taken from PNL-MA-26, *Radiological Control Procedure*, 3.1.05, "Optimization and Cost/Benefit Analysis," Revision 0.

Supporting infrastructure for remote operations will also be a major cost factor. A centralized approach to the management and deployment of remote technology should be carefully considered. The Shelter management team should give serious consideration to development of a remote systems technology center.

5.3 Examples of Remote Technologies

Remote technology in nuclear applications has existed for nearly 50 years and has undergone several generations of evolution. There is no question that there exists an extensive technology base that can be brought to bear on many tasks that must be performed within the Shelter. Practical and well-developed systems and techniques are readily available from equipment suppliers around the world and many new concepts and systems are presently in various stages of development. The purpose of this section is to give the reader some perspective on the technology base available, even though many of them are prototypes. The examples provided here have been selected because they are practical working systems that are relevant to some needs at the Shelter. They reflect the state of the art and exemplify the types of robotic and remote systems technology that can be used at Chornobyl.

5.3.1 Remote Systems versus Robotics

Remote systems, regardless of their degree of automation, can be described in terms of their basic functional structure as shown in Figure 5.1. The human-machine interface (HMI) includes a set of controls and displays that allow the operator to control and communicate with the portion of the system that operates in the remote environment, which is hazardous in some sense. In the case of traditional mechanical master/slave manipulator systems, the "master" side is the set of controls and displays. The

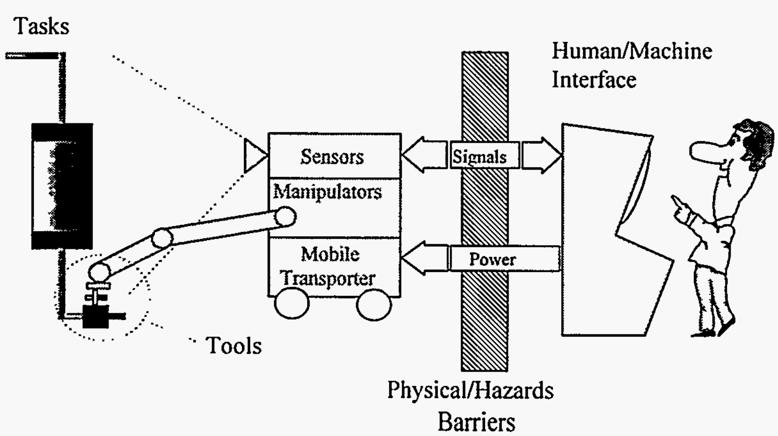

Figure 5.1. Basic Parts of a Remote System

"slave" side includes a combination of subsystems that provide the mobility, manipulation, and remote sensing necessary to allow the overall remote system to perform useful work in the remote task environment.

In addition to these parts, there is also a complex system for the transmission of power and signals between the remote subsystem and the HMI. Signal transmission is a complicated matter because of the large number of signals that must be connected. In the case of modern force-reflecting manipulators, over 100 signal conductors are required for a single manipulator arm. Fortunately, multiplexing and wireless schemes have been developed and refined that make signal transmission workable. Power transmission is more difficult. Most nuclear applications preclude the use of internal combustion engines and the storage efficiency of electrochemical batteries is insufficient for the power consumption of mobile work systems. Power transmission is usually accomplished through the use of power cable tethers, which are difficult to deploy and retrieve.

Modern remote systems are highly computerized. Typically microprocessor-based computational modules exist in both the remote "slave" system and at the "master" operator control station. These microprocessors perform signal processing, communications, and control functions, and implement operator controls and displays.

Radiation protection, such as shielding and hardening are important for protecting delicate electronic components and other materials and lubricants. Hardening refers to shielding or enhancing the component materials so that they are more radiation-resistant.

Another interesting complexity of remote work systems is that they must also carry along the tooling needed to accomplish designated tasks. The manipulator and mobility platform needed for a specific scenario is highly variable, as will be shown in the following examples. In all remote systems, the integration of the various subsystems into a reliable working unit is one the greatest, and often most overlooked, challenges facing designers. Experience has shown that the design of the HMI is a dominant factor in the work efficiency of the overall remote system. Ill-conceived operator controls often can diminish the performance of an otherwise effective remote system.

The term robotics and remote systems are sometimes used interchangeably, which can lead to confusion. Robots are a subset of remote systems and are much newer, having first appeared in the 1960s primarily in association with manufacturing automation. Manufacturing robots are usually much more massive than the traditional manipulators used in remote systems because they are designed to maximize positional repeatability at the expense of size and weight. Robots are designed to replace or substitute manual labor on production lines for economic, safety, or health reasons, performing operations in a fully automated mode under computer control.

Remote systems can also be teleoperated. Teleoperation means the operator controls the system by inputting a manual signal that is transferred mechanically or electrically to a linkage, cable, or motor to control the operations while the operator views these actions on a video display or through a protective window.

In recent times, the distinction between robots and remote systems has diminished as automation concepts are added to the classical concepts of remote operations. Modern remote manipulator systems are often hybrids allowing some computer-controlled functions; from a technical perspective, they are very similar to robots. The remaining key distinction is that robots are normally automated machines generally focused on manufacturing with minimal consideration of manual control functions.

Most real-world remote operations in unstructured hazardous environments, including the early work at the Shelter, is accomplished through manual control or teleoperation. Man-in-the-loop teleoperation[a] ensures that humans are making all of the instantaneous operations decisions. Considerable on-going research is being performed to determine how unstructured remote tasks can be automated reliably for those cases where there is a high degree of task repetitiveness and monotony. It is difficult to imagine any near-term tasks that would justify using fully automated robotic systems in the Shelter; however, there are many potential applications for use of teleoperated remote systems.

Section 5.3.2 describes several systems that are currently available and have been fielded in actual remote operations. Many of these systems are used for applications similar to the types of operations one would expect at the Shelter. Included are examples of robotic and remote systems that have been developed for contamination surveying, excavation of contaminated soils, reactor dismantlement, and explosive ordnance disposal. It should be noted that the systems described here are only a few examples of the remote systems technologies available. This information is provided to give the reader a general sense of the level of capabilities and types of systems available. These descriptions should not be interpreted as an endorsement or recommendation of specific systems. Selection of technologies for the Shelter should involve a more comprehensive review of the available systems following definition of technical requirements.

5.3.2 Characterization Systems

Characterization systems are essentially mobile sensor platforms that are used to perform sensor-based surveys and investigations, some with high degrees of automation. These systems typically have been used to survey for radioactive species, underground objects, chemical compounds, and other materials of interest. Two of the systems described here (MACS and RCS) were developed by the U.S. DOE for environmental restoration applications. Another system, NOMAD, was developed by NASA for planetary exploration and a commercially produced system.

The Mobile Automated Characterization System (MACS) was developed to perform floor radiation surveys in facilities with flat open areas. MACS is shown in Figure 5.2. The pod on the front of the vehicle is an array of six NaI detectors that provide a five-track sweep in front of the vehicle. The mobile chassis is an omni-directional vehicle that is full production. MACS incorporates a laser-based

(a) Man-in-the-loop teleoperation refers to remote systems that are controlled by a person who manually operates controls that send a signal to the equipment via a linkage, cable, or motor while the operator views the process through a window or video monitor.

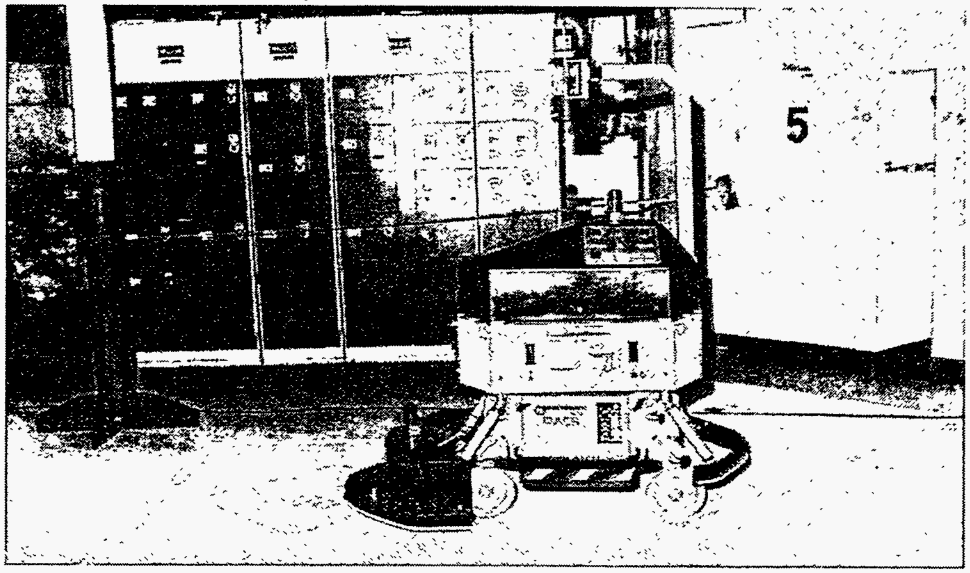

Figure 5.2. Mobile Automated Characterization System

local area navigation system that uses reference markers set up within the area to be mapped. A computerized operator control station is used to set the system for automated survey trajectories based on facility drawings.

MACS has the powerful advantage (in comparison to manual surveys) of being able to creep along the desired trajectory at the constant low speeds required in the survey detection goals. Survey speeds are typically 0.5 to 1 m/min. MACS communicates to the base control station through a radio transmission system that is used to downlink the survey data continuously. Floor surveys are very tedious work; MACS has been designed to perform these surveys autonomously. Several surveys have been performed at the Chicago Pile No. 5 reactor at the Argonne National Laboratory. MACS is limited to operation in clear and flat floor areas but its functionality and architecture could readily be deployed with other mobility platforms for more complex terrain such as some of the areas within the Shelter.

The Remote Characterization System (RCS) was developed to survey buried waste sites within the DOE Complex. In addition to radiation sensors, the RCS also includes ground-penetrating radar and magnetometers for subsurface mapping and detection of buried objects. The RCS is similar to MACS in terms of the provisions for trajectory planning and execution. However it was developed for outside operation in rough terrain by incorporating an articulated wheel drive design. The RCS is navigated through a differential on-board Global Positioning System (which only functions outside). As seen is Figure 5.3, considerable attention was given to the operator control station, which also serves as a remote driving station for operation in complex circumstances where programmed operation is not appropriate.

Nomad is a mobile robot developed by Carnegie Mellon University, NASA Ames Research Center, and others for planetary and terrestrial exploration. The robot uses four-wheel-drive/four-wheel-steer locomotion and an innovative tranforming chassis that expands or compacts the wheel base (see

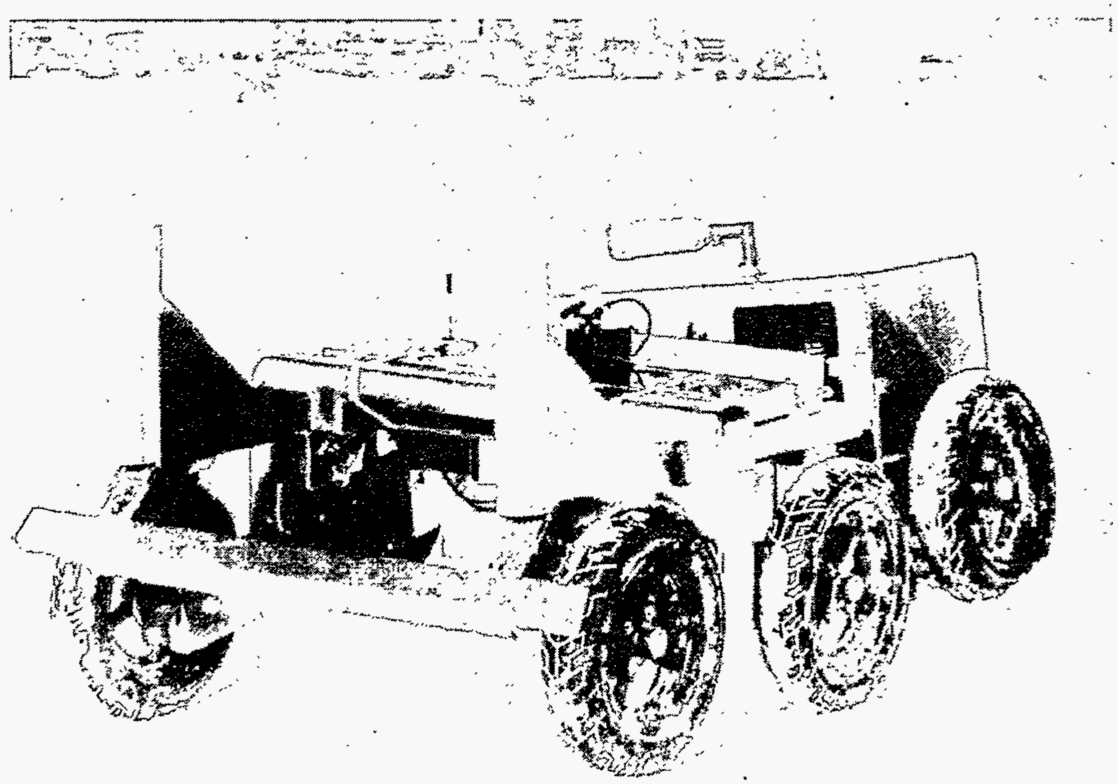

Figure 5.3. Remote Characterization System

Figure 5.4). Nomad carries a panospheric camera that generates broadcast-quality images with an ultrawide field of view. Nomad used active pointing high-gain antennas, instead of a lower-range omnidirectional antenna. Nomad determines its position using traditional sensor-based methods incorporating odometry, inclinometers, a gyrocompass, an inertial measurment unit, and the Global Positioning System as well as a new visual position estimation technology that compares skyline images to an existing terrain map. Nomad's onboard navigation sensors and computing capbilities allow it to reason about obstacles and navigate without operator assistance. Nomad is being field tested in the Chilean desert of Atacama with weather sensors to measure temperature, wind velocity, and humidity; a metal detector; and a panospheric camera with pan/tilt that provides high-resolution color views from 90 degrees below to 30 degrees above the horizon.

Several hundred units of the commercially available mobile robot system shown in Figure 5.5 have been built, primarily for explosive ordinance disposal and police bomb squads. In addition to remote television viewing, the robot has a simple four-degrees-of-freedom manipulator that can be used to handle objects that weigh between 10 and 40 kgs. The articulated track propulsion system gives the robot excellent mobility in rough terrain including stair climbing. The vehicle can be battery or tether powered. All control and sensing signals are transmitted through a fiber optic cable or via radiofrequency control.

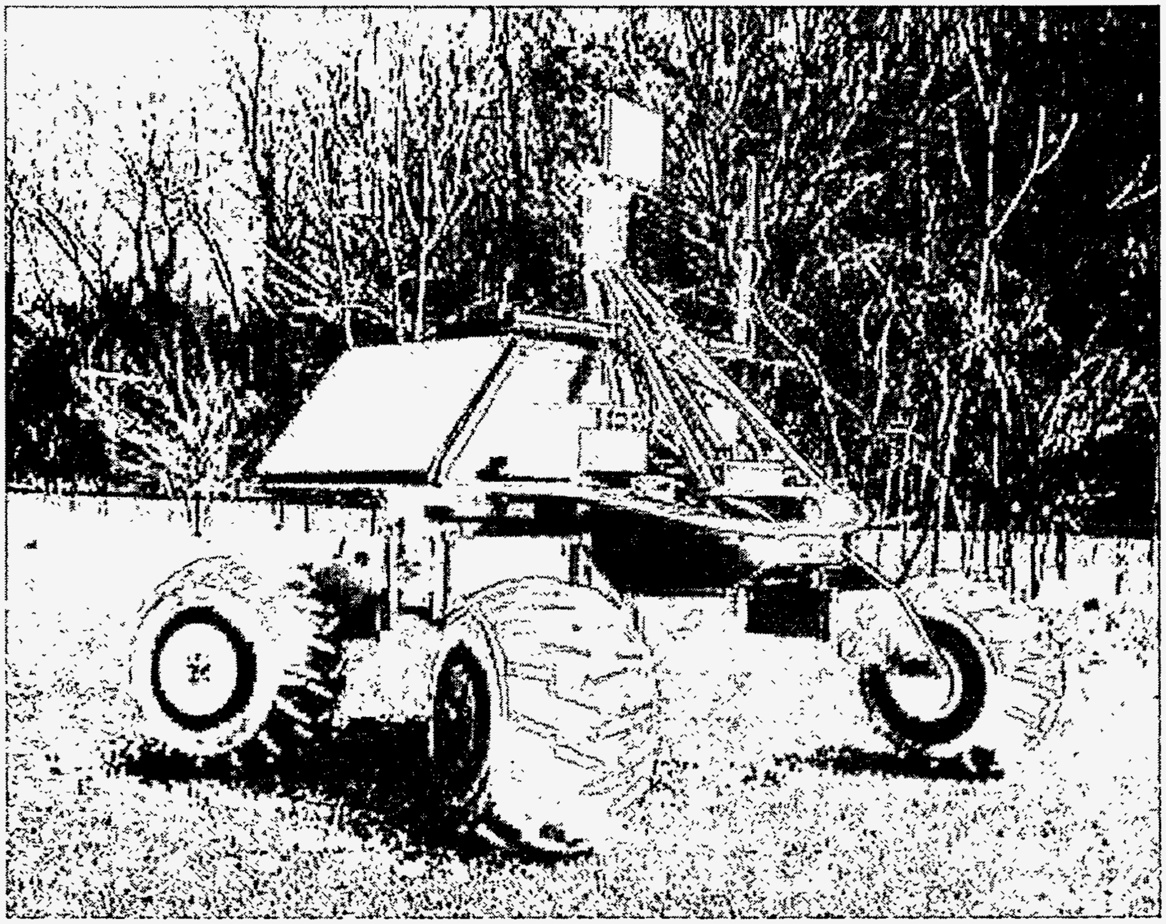

Figure 5.4. Nomad Terrestrial Explorer

5.3.3 Excavation Systems

Perhaps it is useful to think of excavation systems as mobile remote systems that can perform simple manipulation tasks like digging. Several remote excavators have been developed in the United States in DOE and DOD programs. The Teleoperated Small Emplacement Excavator (TSEE), shown in Figure 5.6, was developed as a joint program between the DOE and the DOD. DOE's interests covered remote excavation of buried wastes and contaminated soils while the DOD was interested in remote excavation of unexploded ordnance. The TSEE is essentially a standard four-wheel-drive end loader and backhoe machine that has been retrofitted with sensors, controls, and actuators to allow remote operation from a portable operator control station. The control station was designed to simplify backhoe operation through multi-axis joysticks and graphic display assists. The TSEE has been used extensively by both DOE and DOD in field trials with good results. Many operators report that the remote control of the TSEE is easier to operate than the standard rear-vehicle control station. The TSEE incorporates multiple remote viewing television cameras and wireless signal transmission to the operator control station. As the Army has demonstrated in mock bomb excavation tests, the TSEE can be very precisely controlled

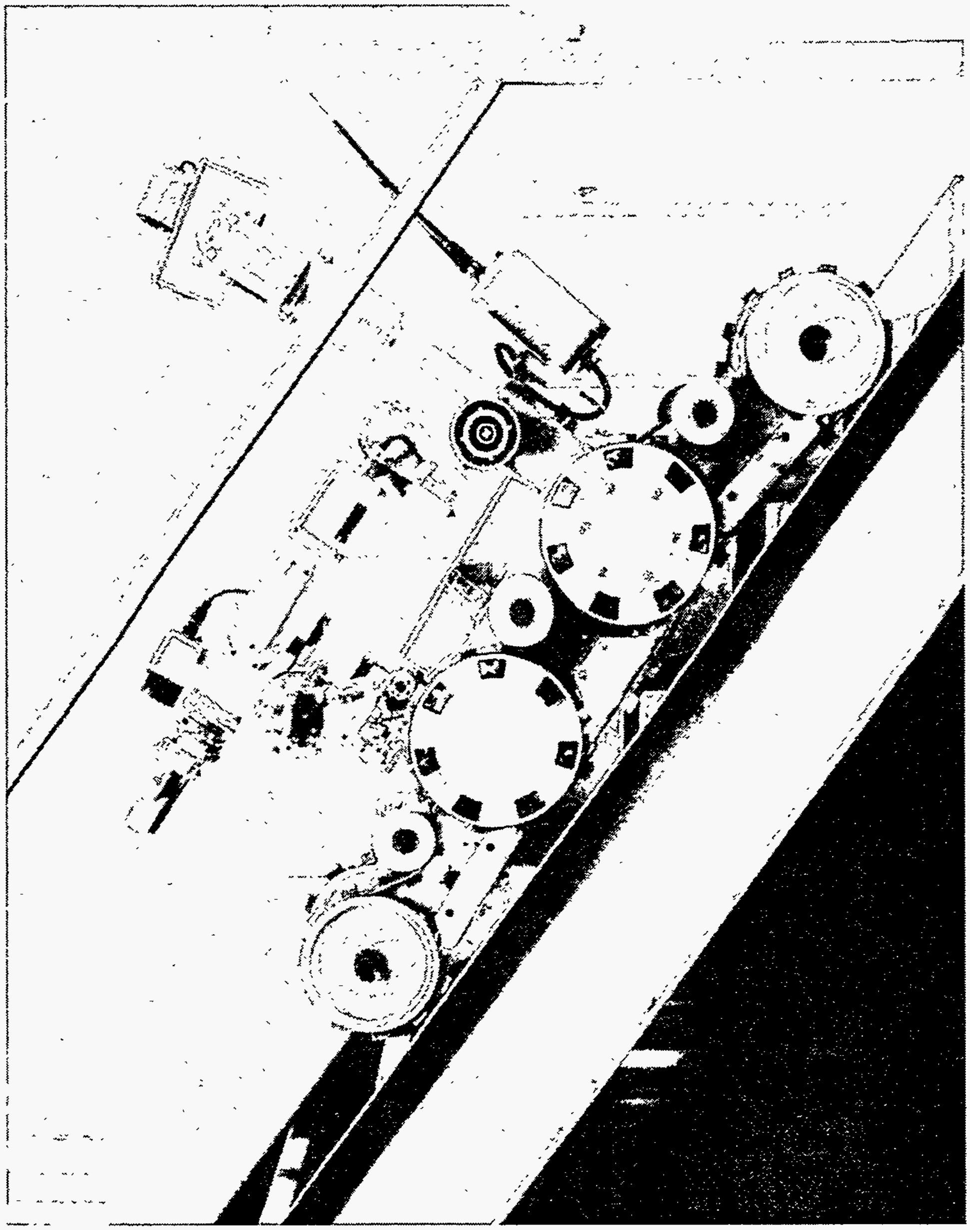

Figure 5.5. Hazardous-Duty Mobile Robot

during digging operations. This level of remote excavation precision would be very useful in debris management within the Shelter.

The mobile robotic vehicle system shown in Figure 5.7 was developed for DOE applications in underground tank waste retrieval. This tracked vehicle is a remotely operated small bulldozer used to push waste materials around to collection points within the tanks. The system is also outfitted with a manipulator arm that can deploy various types of tools to perform remote operations in the tank. The system is hydraulically actuated and consequently has very good maneuverability and power

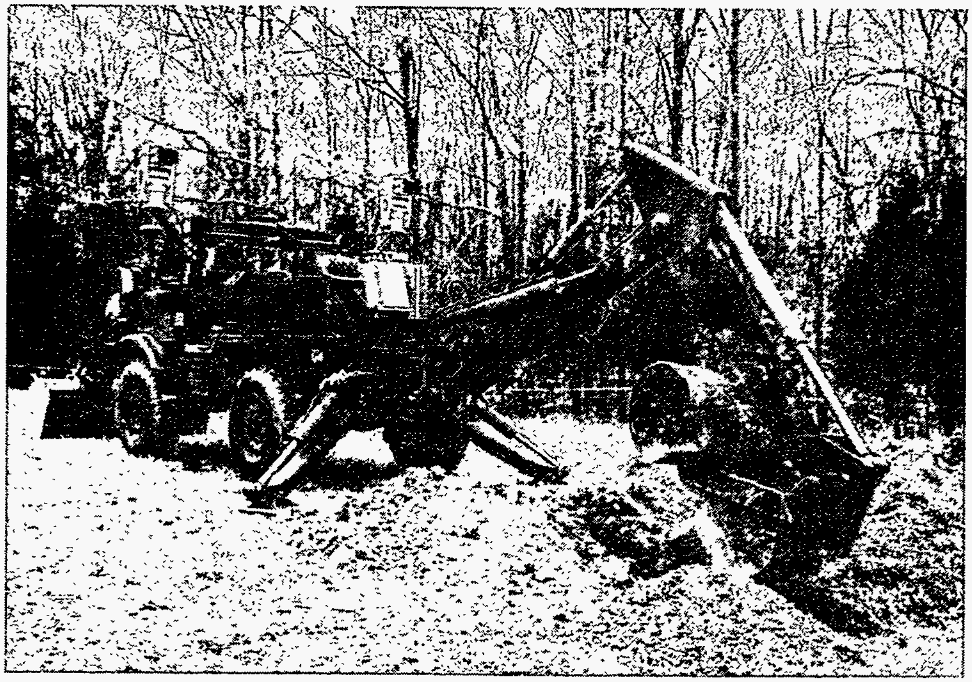

Figure 5.6. Teleoperated Small Emplacement Excavator

performance. Figure 5.7 shows the system operating under simulated waste tank conditions in which it is half buried by the materials it is required to excavate. This system is being deployed at Oak Ridge National Laboratory and will be used in conjunction with an arm-based deployment system to perform waste retrieval operations starting in the summer of 1997. The robot is tether-operated from a remote control station. This system has form factor and propulsion characteristics that may be compatible with the debris management tasks associated with the Shelter.

Figure 5.8 shows a conventional excavator that has been modified for remote operation. The operator uses a single joystick to control the excavator arm, and the master controller has one-to-one correspondence and proportional speed control with the motion of the bucket. This systems was fitted with an end effector consisting of a dexterous thumb, an attachable/detachable integrated transfer module, a shovel assembly and the necessary actuating linkage and hydraulic cylinders. The module acts as a detachable bucket when digging, handling, and conveying 55-gallon drums, dirt, and small debris. The shovel can be moved from a front shovel to a backhoe configuration. The conveyance system includes a track-mounted telerobotic transport vehicle, remote operator control station, and waste transport container. It is propelled by a set of hydraulic motor-powered crawler tracks that provide stability on slopes and good maneuverability. The 4,100-kilogram-capacity waste transport container accepts retrieved waste in the form of 1.25 x 1.25 x 2.4-meter boxes and other large irregular shapes. The transport vehicle uses a state-of-the-art video tracking system along with mission planning software to preplan and then semi-autonomously perform conveyance operations. The system is designed to reduce dust and contamination spread during waste remediation, primarily during dumping and conveyance. The system is demonstrated and ready for deployment.

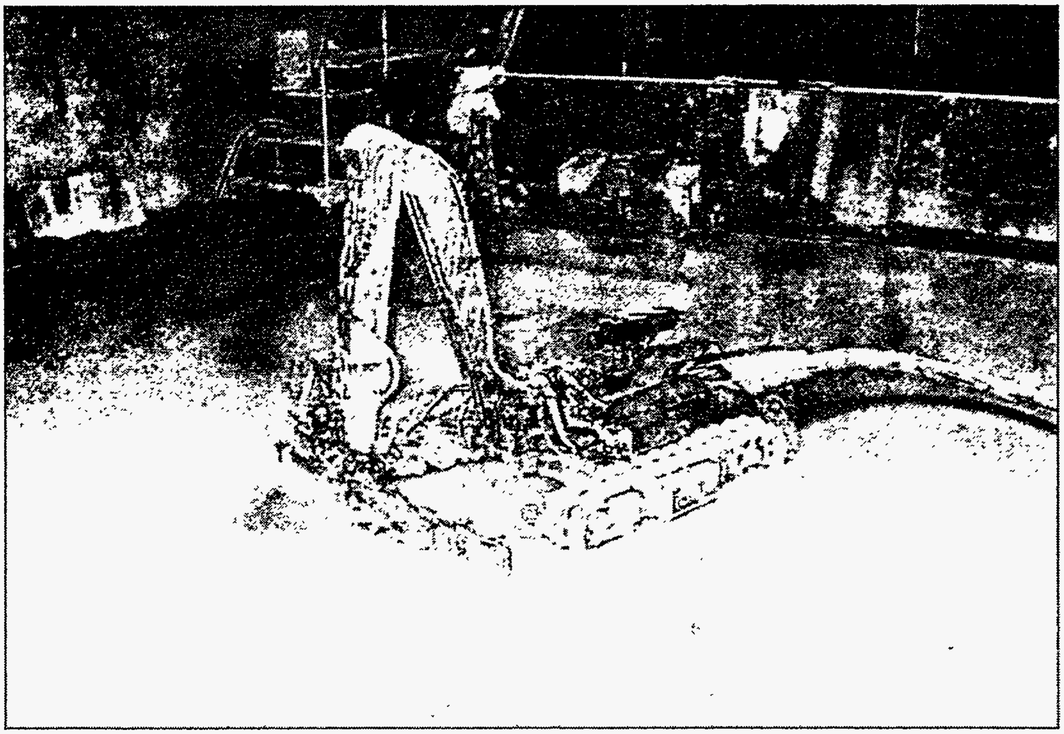

Figure 5.7. Mobile Robotic Vehicle for Tank Waste Retrival

5.3.4 Dismantlement Systems

Several dual-arm work platforms have been developed for use in DOE and European reactor decommissioning projects. Figure 5.9 shows the system presently being used by DOE to dismantle the CP 5 research reactor at the Argonne National Laboratory. Figure 5.10 shows a dual-arm system that has been developed in Europe for use in reactor decommissioning. These dual-arm work platforms use two powerful hydraulic manipulators to perform a range of manipulation operations such as maneuvering various types of cutting tools. Generally these arms can lift up to 250 lbs when fully extended and each arm has a capacity of 1,500 lbs. straight down. The overall system is positioned using a standard overhead crane hook. It has been designed to perform the high payload and rather coarse operations that are generally associated with dismantlement. These systems can incorporate features such as sophisticated remote viewing systems that include head-steered stereo viewing in a design call the "Virtual Window." The VirtualWindow gives the operator the perception that he is looking around in the remote scene in a very natural way with stereo depth perception. The remote manipulation capabilities embodied in these systems are similar to those that will be required to perform the functions identified for Shelter stabilization in the Shelter Implementation Plan.

Figure 5.11 shows a mobile robot work system that can serve as an extendable mobile platform capable of deploying a manipulation package. This system is indicative of the size, complexity, and capabilities of a fully mobile remote vehicle that could be used to perform dismantlement operations

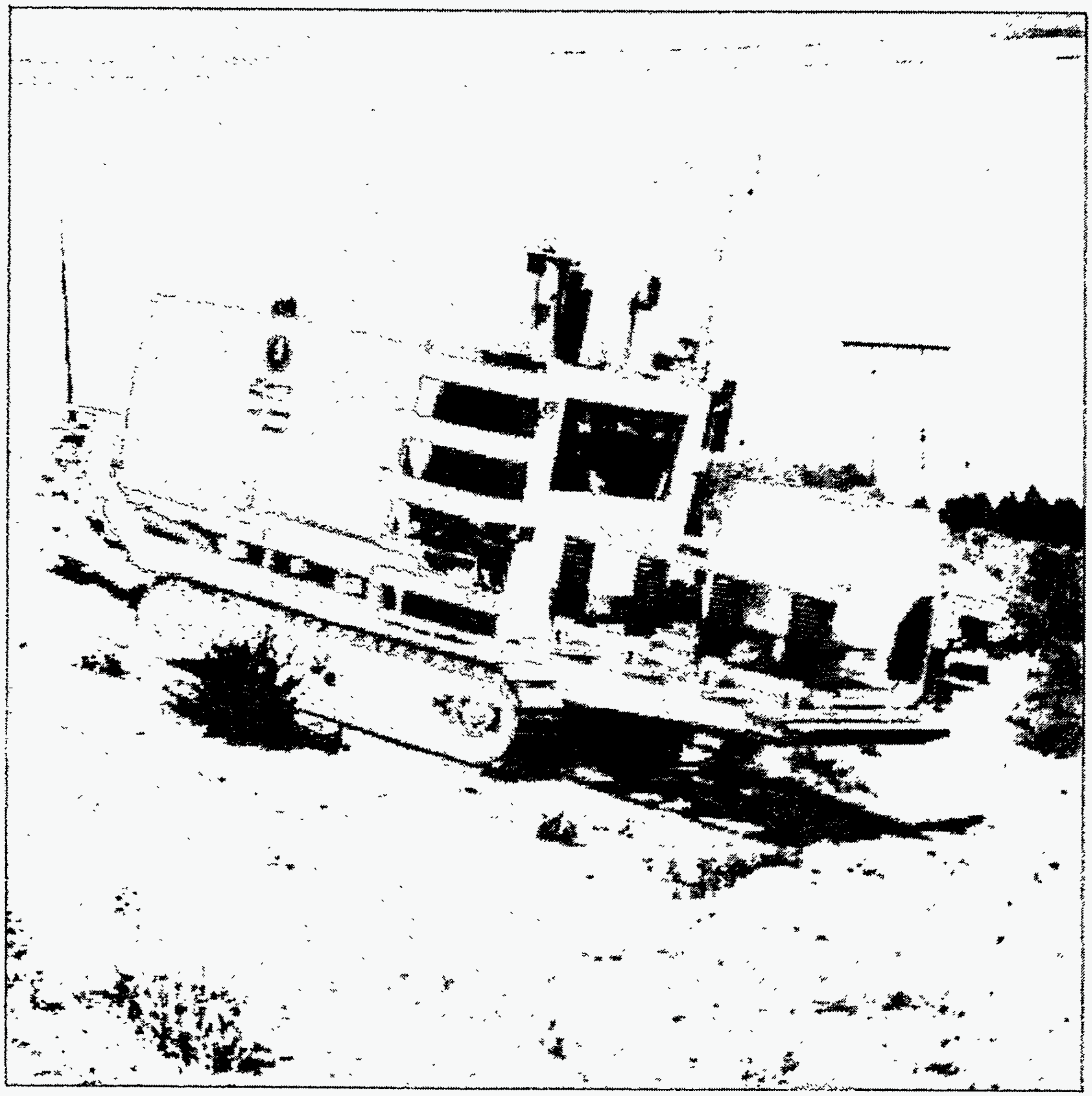

Figure 5.8. Remote Excavation System

over a wide area within a facility. This unit can be used, as it is presently deployed at the CP 5 reactor site, to operate very heavy tools like concrete hammers. It is powered through a high-voltage cable with a servo-controlled tether management subsystem. Two-degree-of-freedom hydraulic drive wheels at each corner provide mobility and permit omni-directional steering. The on-board hydraulic power supply is driven by a 60-hp electric motor.

Figure 5.9. DOE Dual Arm Work Platform

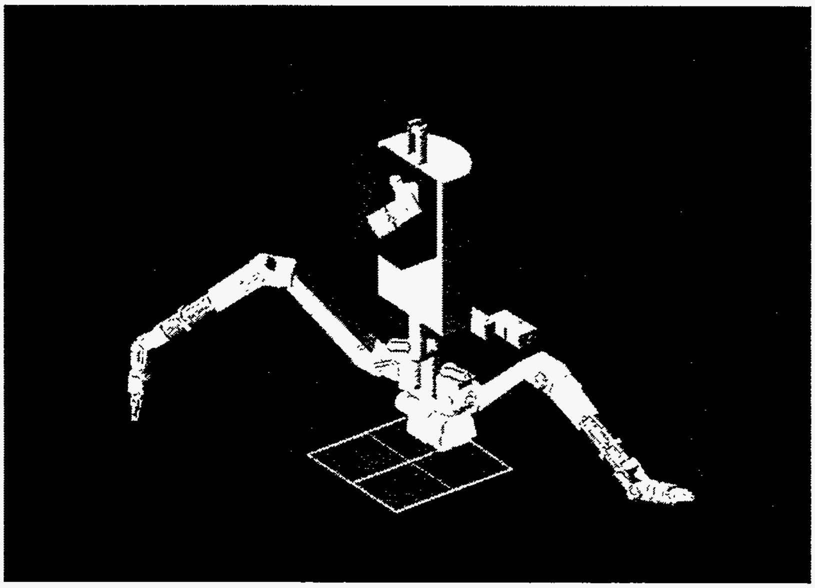

Figure 5.10. European Dual Arm Work Platform

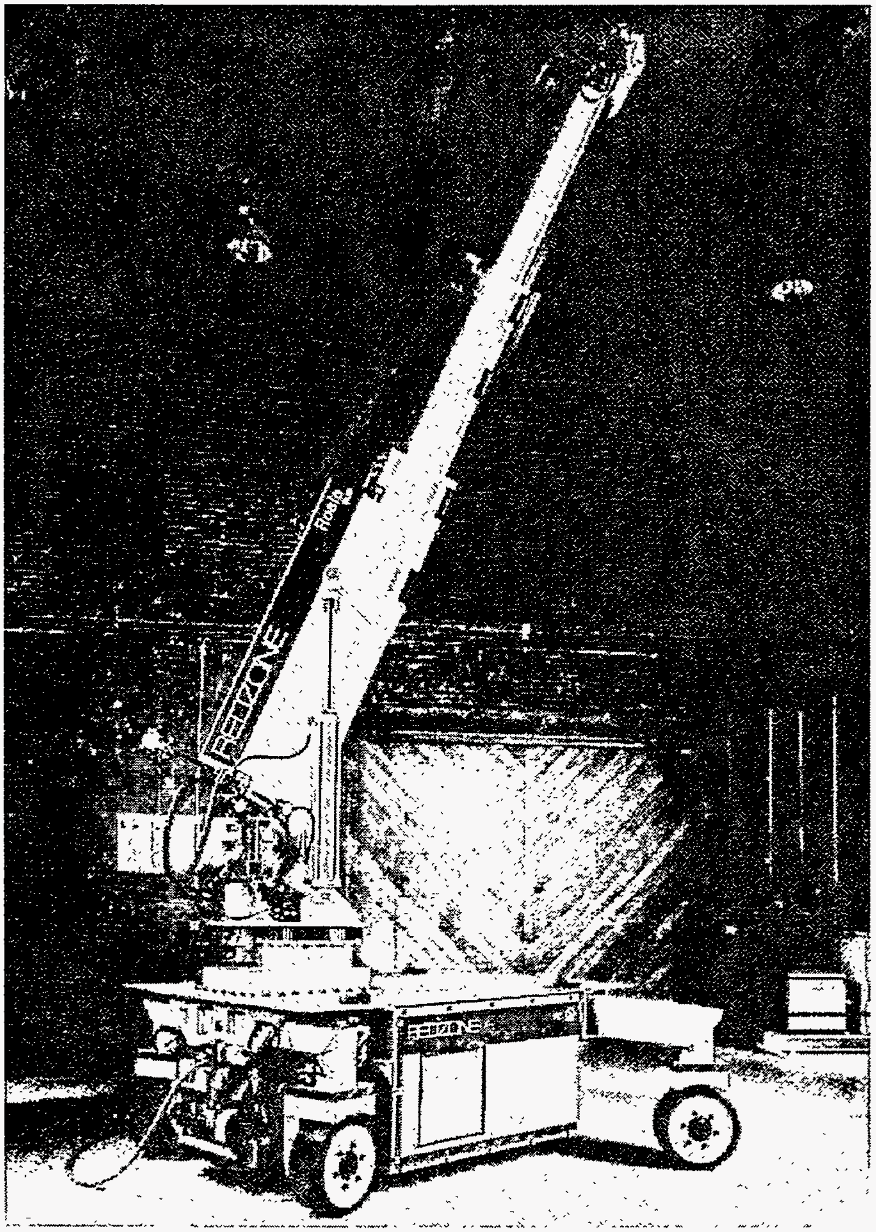

Figure 5.11. Extendable Mobile Robot Work System

5.3.5 Dexterous Manipulation

Some remote manipulation systems are very dexterous and can perform more complex and detailed tasks such as remote welding and disassembly. Requirements for this degree of remote manipulation in the Shelter are not apparent, but in the interest of thoroughness an example of such as system is discussed here. The system shown in Figure 5.12 is a commercially available six-degrees-of-freedom electrical manipulator that can be configured for teleoperation via a manual controller or programmed for robotic operation. It has payloads as high as 100 kg while being able to position control operations

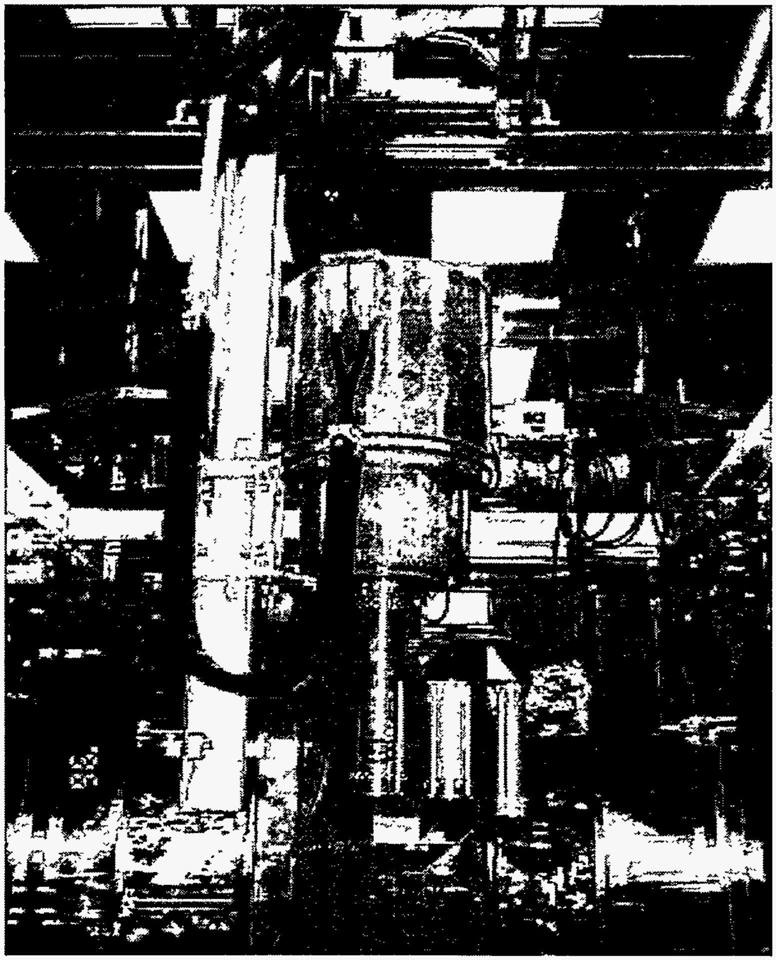

Figure 5.12. German Six-Degrees-of-Freedom Electrical Manipulator

within sub-millimeter precision. This system was recently used in Canada to perform precision repair tasks on CANDU reactors. Figure 5.12 shows its deployment in a hot cell in Japan.

Some of these systems are commercially available and could be used in the Shelter with appropriate modifications. There are many suppliers of similar equipment and technologies around the world. What has been discussed in Sections 5.3.2 through 5.3.5 are but a few examples. Again, we would emphasize that the purpose of this section is not to promote these specific systems, but to use them as examples of the state of the art to fortify the argument that this remote systems technology is readily available and can be adapted for deployment at the Shelter. Generally speaking, considerable work must be done in the area of system integration and special sensing and tooling for particular remote applications of any system concepts including these.

5.4 Current Practice at the Shelter

Current use of remote systems at the Shelter is guided by past experience, where, especially during shelter construction, complex remote systems often failed within days because of the harsh conditions. The ISTC Shelter design philosophy is to minimize complexity in the interest of reliability and ruggedness. This design approach results in machines with narrow remote operational characteristics, which reduces their ability to cope with unexpected remote events. Power and signal transmission is a complicated aspect of a remote system and at the Shelter they have simplified these systems by staging operations very close to the task to be performed. The remote systems are literally carried to a staging area near the task to be performed. The ingress/egress route and staging area are selected to minimize radiation exposure. This approach has the advantages of keeping the tethered cabling short and having the operating crew physically near the remote system. The disadvantage is, of course, the radiation exposure resulting from porting the equipment into the work area and operators working in the vicinity of high radiation areas. Many western remote operations would use much longer "standoff" distances that virtually eliminate operator exposure. Also, the equipment would be driven into position under remote control rather than being carried into the deployment site. An "as low as reasonably achievable" (ALARA) worker exposure philosophy motivates the idea of full remote operation including ingress/egress.

The ISTC Shelter organization is developing prototype robotic systems to perform a variety of diagnostic and access clearing tasks. Most of these systems use a common base platform that provides very good turning capability. The ISTC–Shelter organization works with very limited resources and facilities that lack the space and infrastructure to really perform good testing of the systems. Considerable hardening and upgrades to these systems would be required to actually field them in the Shelter. However, the staff at the ISTC–Shelter have good capabilities and should be considered a valuable resource in future planning for obtaining and deploying systems to implement the Shelter Implementation Plan recommendations.

The photographs shown in Figure 5.13 were taken in May 1997, during an informal demonstration of the prototype systems for the review team at the ISTC's facility located in the town of Chornobyl. Dr. Alexander Ivanov, Director of this facility, highly praised the dedication and resourcefulness of his staff working under very difficult circumstances. He stressed that it is difficult to attract good technical people to work there, because of the working conditions, poor facilities, and lack of funding.

5.5 Current Initiatives

The following are various remote system projects related to the Shelter that are under development and were started prior to publication of the Shelter Implementation Plan.

One initiative currently underway for the Shelter is the "Pioneer" project. This project brings together a consortium of participants to deliver a western style remote system for use within the Shelter. DOE and NASA are jointly funding the program. NASA's interest in the project is to use a terrestrial

Figure 5.13. Prototype Robots Developed at Chornobyl

analog to obtain data and experience that could be applied to projects related to characterization and sampling on asteroids or planets. .

The goal of this effort is to deliver a remote system based on an existing platform to perform structural assessment tasks within the Shelter. The Pioneer system would be based on the Houdini remote vehicle described in Section 5.3 and will provide the capabilities of a Class 1 machine. The system will be equipped with sensing and diagnostic technology from the NASA laboratories. The system will include a coring capability, allowing the system to drill through concrete to determine structural characteristics and physical properties. In addition, it will carry environmental sensors to measure parameters such as radiation, temperature, and humidity. The Pioneer system should provide the capabilities to perform required diagnostic and limited payload stabilization activities as defined above. The program is scheduled to deliver the system to Ukraine in early 1998.

There is currently a DOE cooperative research and development agreement with the RITM Institute at the National Technical University of Ukraine, "Kyiv Polytechnical Institute," to develop a pipe-cutting robot to be used in the Steam Distribution Corridor to remove piping to clear access. This work is funded through the DOE-Office of Nulcear Nonproliferation (NN) International Proliferation Prevention Program. The RITM scientists have developed a prototype vehicle system that is being tested at the University in Kyiv. A cutting head is attached to the mobile platform that can be raised or lowered to various elevations. Testing with both high-pressure waterjet cutting nozzles and laser cutters have been tested. The system is developmental and there are no current plans to deploy this unit. Significant work would have to be done to configure and harden it for actual field deployment.

5.6 Lessons Learned

Applying lessons learned from prior experience with remote systems previously deployed at the Shelter and from nuclear applications in government-run and commercial facilities will be very valuable in planning for future deployments of remote technologies at the Shelter. Several problem areas have been identified in deployment of remote technologies in the Shelter including failure of systems due to radiation exposure damage, entanglement with debris, and lack of robustness to withstand the environment. Prior experience needs to be further analyzed in planning for upcoming projects to ensure that the lessons learned will benefit new applications.

DOE has undertaken a number of decommissioning and dismantlement demonstrations that could provide valuable lessons for Chornobyl. One example currently underway is the dismantlement of the Chicago Pile (CP)-5 reactor at Argonne National Laboratory in Chicago. CP-5 is a small research reactor; its dismantlement embodies many of the fundamental operations that would be required at the Shelter. Examples are cutting operations, material handling, and characterization surveys of the environment. The activities at CP-5 have demonstrated the importance of training and cold prototyping, which should be applied at the Shelter. Having a mockup or non-contaminated prototype system to support troubleshooting deployment problems and to support design modifications, expansion of applications, and training can be very valuable in supporting remote systems implementation.

Remote operations are extensively used throughout the DOE Complex in operating nuclear facilities and in the cleanup of waste sites. Experience has shown that having an inventory of standard equipment that can be utilized for future and unplanned needs is very cost-effective and can minimize down-time for maintenance and repairs. Having on hand a supply of various camera systems and modular robotic components that can be configured for various applications can enable quick and inexpensive response to unplanned situations or new requirements.

The problem of radiation hardening of equipment for nuclear applications is common through all types of nuclear applications. There are generally two approaches to this problems: either using radiation-tolerant systems or using relatively inexpensive modular components that can be easily replaced. Radiation-hardened systems are often expensive, so the decision generally comes down to a cost/benefit tradeoff. In many cases, for systems that are not permanent installations in high radiation areas, the use of modular components proves to be the most cost-effective approach.

Planning for recovery from system failures is an important area to be considered in selecting technologies and implementing successful deployments. As systems become more complex, redundancy becomes more necessary to avoid extensive downtime and personnel exposure to recover or repair systems. Incorporation of redundancy or investing in more costly components to improve reliability is another area to be evaluated through a cost/benefit tradeoff analysis. Training for off-normal events and having in place procedures or guidelines for responding to system failure will both improve operations and reduce risks to personnel.

The response and cleanup at the Three Mile Island plant is another example where the application of remote systems may provide valuable lessons learned.

The examples provided here discuss only a few of the lessons learned from prior experience that can benefit planning for remote systems deployment at the Shelter. There are numerous other lessons learned from prior experiences in the commercial and government-sponsored nuclear industries that could be applied to the challenges of Chornobyl. Consideration should be given to forming a working group of Shelter staff, who understand the problems and conditions of the Shelter, and remote technologists, who have experience working with and testing remote systems in actual field conditions. This working group could further define the fundamental robot and remote systems capabilities necessary to meet the remote task requirements that have been outlined in this document. Based on their experience, this working group would provide valuable input needed for defining the technical specifications to be included in the eventual EBRD tenders or specific remote systems acquisitions.

6.0 Infrastructure Requirements

Infrastructure is the collection of human resources and facilities necessary to realize and deploy remote systems effectively at the Shelter. Within the local ChNPP organizations (i.e., the Shelter and/or other operating units) there must exist high-quality technical staff resources, test and evaluation facilities, and training programs and facilities to ensure that good systems are developed and procured and that they can be operated safely and successfully. These needs are described below. The establishment of a central facility to meet these needs is recommended.

6.1 Remote Systems Technology Facility

The concept of establishing a centralized remote systems technology facility to support multiple projects and act as a resource for shared information appears to be a worthwhile consideration. The systems, when provided, can become an operational resource to multiple projects, if the requirements are appropriately defined up front to include multiple mission considerations. At this centralized facility remote technologies could be integrated and tested, and operators could be trained prior to deployment. This facility would coordinate and manage remote applications in the overall ChNPP including decontamination, dismantlement, decommissioning, and radioactive waste handling operations associated with Units 1, 2 and 3 as well as the Unit 4 Shelter. The establishment of a common facility where these activities are performed will likely reduce duplication in developing individual separate testing sites. Such a facility could also be a resource to support decommissioning activities at the other Chornobyl units as that work progresses. This facility should include technical experts with a background in implementation of remote technologies or should be supported in an advisory capacity by an independent team of advisers with such backgrounds.

The major disadvantage of this approach is, to some extent, it may conflict with the project tendering philosophy of the G-7 working group and EBRD to place fixed price contracts for conducting the work defined in the SIP tasks. The EBRD will retain a project management unit (PMU) via tendering and will also place contracts with engineering performance organizations (EPOs) to conduct the actual work. The successful contractors for this work will want the latitude to choose their own systems, including remote technologies, to maximize their control of the work scope. One potential solution may be to consider chartering the project management unit with the responsibility to coordinate the need and capabilities definitions as well as to support the technology identification process. This might include subcontracting with firms to develop capabilities and systems that would support multiple projects.

6.2 Human Resources

Engineering and technical specialists in the areas of remote engineering, electronics, and digital systems and software are required. Specialists with capabilities in the areas of remote viewing and sensing and radiation and environmental hardening will also be a critical resource. The number of specialists required is a function of the number of systems being deployed, taking into account scheduling and concurrent operations. Remote systems operators should be identified and screened using well-established selection criteria and testing.

Consideration should be given to establishing a supporting consulting board made up of independent remote systems experts, not affiliated with the commercial industry suppliers of systems. This board could serve to provide advice on a consulting basis to support both the Shelter Operations and the EBRD without potential conflict of interest situations arising. The key decision makers in defining requirements, planning, and selecting remote systems should be people who actually have experience with remote equipment in the field. The advising group could provide specific technical expertise to supplement the capabilities of the large group.

6.3 Cold Testing Facilities

Non-radioactive, or cold, testing facilities where the full-scale remote systems can be pre-tested for deployment at the Shelter must be provided. Cold testing is performed with full-scale and functionally realistic mock-ups of the actual tasks expected in the Shelter. This type of testing is critical for pre-qualification of the equipment, procedures, and operators. The cold test mock-ups also provide operational support for the analysis of unexpected events in the actual hot mission. Usually, the Cold Test Facility will be a high-bay type work area with a complement of handling and service equipment suitable for full-scale testing. Supporting staff to help with test setup, equipment installations, modifications, and other tasks related to the test program will also be required. The site for test facilities should be carefully chosen to allow ease of use by the operations and engineering organizations that will be performing the work.

6.4 Training Programs and Facilities

These facilities are normally integrated into the Cold Test Facility. Programs that provide standardized approaches for operator selection and training are used for initial orientation. Design familiarization tailored to the level of technical background and education of the operations crew should be included to ensure a depth of understanding beyond just operating the specific equipment controls. This type of training will better equip operators to deal with unexpected circumstances or off-normal events, as well as understanding the capabilities and limitations of the equipment. Use of computer-based simulation programs is a valuable tool for use in evaluating alternatives, pre-planning jobs, and training for specific operations. Systems for operator observation and evaluation (e.g., video recording, etc.) are necessary to systematically evaluate operators. Validation of operating procedures should also be an integral part of the training and system qualification program. Co-located or nearby facilities for testing and training would be cost-effective and provide opportunities for incorporating training activities into the testing programs.

6.5 Maintenance Facilities

The maintenance infrastructure for test and measurement equipment, decontamination facilities, and for contaminated equipment must be provided. These facilities will be most likely closely coupled to the Shelter location where the operations actually occur. Evaluating strategies in obtaining systems that maximize commonality in designs and components could significantly reduce costs for parts and maintenance, but may be difficult to achieve. Training for maintenance operations should be built into the testing and training programs, to enable operations staff to get hands-on experience with equipment in a cold environment prior to deployment.

6.6 Facility Access and Services

As discussed above in Section 2.2.3, the accident has left the Shelter with significant problems related to providing access to work areas and the utility services required to support operations. Improvements to the Shelter to provide access and the necessary power, lighting, and other services determined in establishing system requirements must be planned and implemented to support equipment deployment. Access schemes are under development and should be reviewed to ensure they meet the requirements for deploying remote systems.

7.0 Recommendations and Conclusions

The findings of this assessment confirm the need for application of remote systems technologies, including robotics, to support day-to-day operations in the Shelter and implementation of both short- and long-term stabilization and remediation tasks defined in the Shelter Implementation Plan.

The remote systems technology needs assessment has been conducted with two major objectives. The first objective was to evaluate requirements for remote systems at the Chornobyl Unit 4 Shelter to perform various tasks for stabilization of the facility. The second objective was to evaluate the needs for a technology facility for system development, testing, and operator training prior to Shelter deployments. These two objectives have been met through the mapping and analyses of requirements listed in the Shelter Implementation Plan and described by Shelter Operations staff.

7.1 Recommendations

The following actions are recommended to promote a strong and effective technology deployment program at the Shelter. These recommendations should be considered in preparing specifications and requests for proposals for biddable projects that will be tendered by the EBRD to implement the Shelter Implementation Plan tasks.

- *Use a step-wise approach starting with simple and robust technologies.*

  It is absolutely imperative that the first systems deployed in a new remote operations initiative at the Shelter be successful. Success criteria may vary from group to group or among individuals, but it primarily comes down to systems performing their missions reliably and as designed. Sure winners are likely to be the simplest technologies or those that have proven records of reliability under similar test or field conditions. There are many instances where poor initial remote deployments have had severe and lasting negative consequences. On the other hand, positive initial deployments can lead to greater innovation and positive benefits. The interviews with the Shelter operating staff (which is indicative of most operating people) indicated that they are skeptical of advanced technology especially when it involves "bells and whistles" that go beyond fundamental needs. It is not likely that they will have much sympathy or interest in systems that do not operate properly or reliably. The first few projects must be solid winners else remote systems will only be used for those situations where radiation levels and hazards are life threatening.

- *Initiate early remote systems projects focusing on high-priority near-term needs.*

  The analysis of Shelter Implementation Plan tasks, remote operations, and system classifications and priorities clearly identified the near-term need for remote systems that can perform diagnostic investigations to support structural assessment as well as FCM and environmental characterization. The work under the current Pioneer project should be closely aligned with these requirements and should be directed at providing a diagnostic platform that can support deployment of multiple sensors. To get the most benefit from this investment, the system should be directed to high-priority, near-term need areas as described in this document. Investigation of alternate systems that could support or supplement the capabilities of Pioneer should be considered, as one platform is unlikely to provide all the capabilities required for the diverse environment of the Shelter. It is clear that there are fundamental needs for remote systems that can be used for clearing debris and preparing access for personnel and other remote technologies. A quick start initiative should be considered to define the requirements and begin acquisition of such a system. This should be closely coupled to the ongoing efforts to define access schemes that are currently being developed by Shelter Operations.

- *Develop detailed system functional and technical requirements.*

  The fundamental basis for successful acquisition and deployment of remote systems at the Shelter will be development of detailed system functional and technical requirements. Applying a systems engineering approach to establishing requirements will lead to a sound basis for future project work. The investment made in researching the details up front and defining clear requirements will be more than paid for in reduced costs for system development and acquisition. Establishing a centralized coordinated effort to define system technical and interface requirements will not only be the most cost-effective approach but will reduce safety and operational risks in deployment. Due to the broad range of operations and tasks to be performed, very careful task parameterization must be done to prioritize the required technology. More specific definition of tooling requirements must also be established. Consideration should be given to sponsoring an invited technical specialists working group to further define the fundamental robot and remote systems capabilities that are necessary to meet the remote task requirements that have been outlined in this document. The working group would provide needed input for defining the technical specifications to be included in the eventual tenders, or specific remote systems acquisitions required for the work performed by the EPOs. The working group should be comprised of Shelter staff, who understand the problems and conditions of the Shelter, and remote technologists from laboratories and universities.

- *Establish integrated management.*

  Provide an integrated approach to the management of remote technology initiatives. Provide a centralized liaison with remote technology suppliers from around the world and ensure that work is not duplicated among projects. Work with the PMU to establish a coordinated remote systems approach that will support the project tendering process. As discussed in this report, remote systems requirements crosscut the Shelter Implementation Plan tasks and a centralized project management for coordination of the planning, acquisition and deployment of remote systems should be considered. Requirements should be analyzed for commonality, so that investment in remote systems can meet multiple project needs. This will streamline training and operational support, by establishing common system features and interfaces. The leadership of this effort should focus on the creation of general interface and functional requirements, and guidelines for operator interfaces and controls, so that operators can more easily learn controls for multiple systems and avoid operator errors caused by switching between systems. A central technical database related to the requirements, facility interfaces, and human machine interface considerations for remote systems should be established that can be referenced and used for remote systems projects to promote consistency of approach and reduce costs for requirements definition. Consideration should be given to establishing a supporting consulting board made up of independent remote systems experts, not affiliated with the commercial industry suppliers of systems. This board could serve to provide advice on a consulting basis to support Shelter Operations, the PMU, and the EPOs without potential conflict of interest situations arising. The key decision makers in defining requirements, planning, and selecting remote systems should be people who actually have experience with remote equipment in the field. The advisory group could provide specific technical expertise to supplement the capabilities of the large group.

- *Thoroughly investigate available remote technology.*

  Perform a comprehensive investigation of all of the available remotely operated vehicle systems that could potentially support various needs in the Shelter. Additional investigations of alternate approaches and remote technologies other than vehicles should to be included to address operational areas that are not amenable for vehicle access. Document information on commercial systems available internationally, as well as their field performance track record, and make this information available to the Shelter Operations organization, the PMU, and the EPOs to support various Shelter Implementation Plan tasks. Issuing a call for information based on a solicitation identifying the needed capabilities could be one method of obtaining data on current technologies. This information could be reviewed and compiled by the independent consulting board suggested above.

- *Establish remote systems technology facility.*

  As discussed previously in this report, in order to facilitate successful development and deployment of remote systems for the Shelter, a remote systems technology facility should be established where testing, equipment qualification, operator training, and operations support to all projects can be provided. This facility must have a close working relationship with the Shelter Operations organization and technical institutes or companies providing systems. In order for the remote systems facility to be effective, its relationship with Shelter Operations must be integrated with and directly linked to their activities and priorities.

- *Plan for supporting infrastructure.*

  A detailed plan to improve the Shelter infrastructure should be developed to support deployment of remotely operated equipment. This is linked to the previous recommendation in regards to the need to improve testing and training facilities required to prepare for field deployment. Installation of needed plant-operating infrastructure such as providing for safe access and services including lighting and electrical power should be addressed. Establishment of maintenance facilities and training of staff who will troubleshoot and maintain systems is a very important area that needs to be addressed.

7.2 Conclusions

The overall conclusion is that there are many needs for remote systems in the Shelter to provide assistance in the areas of inspection and monitoring, debris management, material handling, deconstruction, construction, excavation, and equipment installation/repair. These systems need to be carefully implemented in a step-wise approach beginning with simple robust systems to prove the viability and usefulness of remote systems with respect to "getting work done" as well as reduction of dose uptake by site staff. In order to deploy such systems within the evolving regulatory environment, a technology center is needed in Ukraine to support development, testing, and operator training in an integrated fashion to ensure success.

Remote systems should play a role in significantly reducing the dose uptake to personnel working in the Shelter and provide the capability to perform work not previously possible due to the hazard levels. The successful implementation of remote technologies will depend on careful planning and development of definitive functional requirements and design criteria that accurately reflect the nature of the work to be performed and the challenges of the operational environment. It is recommended that the application of robotics and remote systems be approached in a stepwise fashion, starting with simple and robust technologies applied in readily accessible areas where operations can be tested. Experience thus gained in operating systems and lessons learned on system performance can be applied in expanding applications to more sophisticated equipment and challenging areas. Testing of systems in simulated conditions and training for personnel to operate the equipment in the Shelter are important factors to achieve successful remote operations. Improvement of testing and training facilities and infrastructure enhancements at the Shelter will be needed to support deployment of remote systems technologies.

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Appendix A

List of Persons Interviewed

Appendix A

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Appendix B

Composite Remote Task Summary

Table B.1. Composite Remote Task Summary

Requirements from Shelter Implementation Plan		Requirements from Shelter Operations	
Task Area	Remote Task Requirements	Task Area	Remote Task Requirements
Structural Stabilization Task Group (Tasks 1-8)			
Task 1: Stabilization and Shielding Design Integration & Mobilization	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • radiation surveys • shielding decon		
Task 2: Western Section	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • structural inspection • materials transport • installation of structural stabilizers • radiation surveys • shielding decon		
Task 3: Mammoth Beam and Southern Section	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • structural inspection • materials transport • installation of structural stabilizers • radiation surveys • shielding decon	Structural Investigations of B1, B2, and Mammoth (Highest priority)	• transport and install sensors • visual inspection and nondestructive testing • position determination • store/retrieve/display data
Task 4: Eastern and Northern Sections	• debris clearing • ingress/egress route preparation • installation of shielding and utility services • structural inspection • materials transport • installation of structural stabilizers • radiation surveys • shielding decon	Short-Term Stabilization	• reinforce ventilation stack

Requirements from Shelter Implementation Plan		Requirements from Shelter Operations	
Task Area	**Remote Task Requirements**	**Task Area**	**Remote Task Requirements**
Task 5: Roof, Roof Supports, and Covering	• on-roof radiation surveys • inspect existing structure • stabilize existing structure • construct/install new roof structure • high loads and long reaches	Short-Term Stabilization	• seal existing roof • on-roof radiation surveys • inspect existing structure • cutting and welding on roof
Task 6: Structural Investigation & Monitoring	• transport and install sensors • visual inspection and nondestructive testing • position determination • store/retrieve/display data	Structural Investigations (Highest priority)	• transport and install sensors • visual inspection and nondestructive testing • position determination • store/retrieve/display data
Task 7: Geotechnical Investigation	• NO REMOTE TASKS		
Task 8: Seismic Characterization & Monitoring	• NO REMOTE TASKS		
Collapse Accident Consequence Mitigation Group (Tasks 9-11)			
Task 9: Emergency Preparedness	• reconnaissance operations • rescue operations		
Task 10: Dust Management	• air sampling • visual inspections • local application of dust fixatives • collect and package dust material • filter changing, packaging, and transporting	Dust Management	• measurements to characterize flow paths • air sampling • visual inspections
Task 11: Emergency Dust Suppression System	• installation of suppressant delivery equipment (i.e., pipes, pumps, etc.)		
Improve Nuclear Safety Task Group (Tasks 12-14)			
Task 12: Criticality Control & Nuclear Safety	• ingress/egress to FCM locations • install/deploy sensors	Radiation Safety	• install criticality monitors • access drilling/boring
Task 13: Contained Water Management	• liquid sampling and transport • drill bore holes	Contained Water Management	• measurements to characterize inlets, outlets, and flow paths

Requirements from Shelter Implementation Plan		Requirements from Shelter Operations	
Task Area	**Remote Task Requirements**	**Task Area**	**Remote Task Requirements**
Task 14: Fuel Containing Material (FCM) Characterization	• ingress/egress to FCM locations • measure alpha, gamma, and neutron radiation • visual imaging • core drill and sample • package and transport samples	Fuel Investigations	• sample and map FCMs in Room 305, Steam Separator Room, and the Central Reactor Hall • ingress/egress to FCM locations • ingress/egress preparations • measure alpha, gamma, and neutron radiation • visual imaging • core drill and sample • package and transport samples
Improve Worker Safety Task Group (Tasks 15-18)			
Task 15: Radiological Protection Program	• NO REMOTE TASKS		
Task 16: Industrial Safety, Fire Protection, Infrastructure and Access Control	• pre-operational safety inspections		
Task 17: Integrated Monitoring System	• NO REMOTE TASKS		
Task 18: Integrated Database	• NO REMOTE TASKS		
Long-Term Strategy and Study for Conversion to an Environmentally Safe Site Tasks (Tasks 19-22)			
Task 19: FCM Removal and Waste Management Strategy and Study	See Task 20		• Physical and radiological mapping of the Central Reactor Hall
Task 20: FCM Removal Technology Development	• ingress/egress to FCM locations • FCM mapping and analysis • FCM size reduction, special tooling • FCM and waste sorting, handling, packaging and transporting • monitor dust control and criticality		

Requirements from Shelter Implementation Plan		Requirements from Shelter Operations	
Task Area	**Remote Task Requirements**	**Task Area**	**Remote Task Requirements**
Task 21: Safe Confinement Strategy	• large scale dismantlement • overhead and ground-mounted operations	Buried Waste Removal	• survey and map buried wastes • excavate and sort overburden • package contaminated soils
Task 22: Implementation of Safe Confinement Strategy to Support Deconstruction and FCM Removal	See Tasks 20,21		

Appendix C

Summary of Shelter Implementation Plan Task Schedule and Estimated Costs

Appendix C

Summary of Shelter Implementation Plan Task Schedule and Estimated Costs

Table C.1. Summary of Shelter Implementation Plan Task Schedule and Estimated Costs

Task	Estimated Cost, $K	Schedule	
		Start Date	End Date
1 Stabilization and Shielding Design Integration and Mobilization	$62,327	1/1/97	8/31/98
2 Stabilization and Shielding of the Western Section	111,535	1/1/97	5/30/01
3 Stabilization and Shielding of the Mammoth Beam and Southern Section	24,817	1/1/97	5/30/01
4 Stabilization and Shielding of the Eastern and Northern Section	10,466	1/1/97	5/22/01
5 Stabilization of Roof, Roof Support, and Cover	33,426	9/1/97	4/24/01
6 Structural Investigation and Monitoring	2,234	5/1/97	3/31/05
7 Geotechnical Investigation	1,192	5/1/97	5/21/98
8 Seismic Characterization and Monitoring	1,354	6/2/97	4/14/99
9 Emergency Preparedness	880	4/1/97	3/31/05
10 Dust Fixation	13,676	8/1/97	3/26/03
11 Emergency Dust Suppression System	28,126	1/1/97	9/3/03
12 Criticality and Nuclear Safety	12,588	1/1/97	3/31/05
13 Contained Water Management	25,779	1/1/97	8/4/00
14 Fuel Containing Materials Characterization	10,545	6/2/97	5/11/00
15 Radiological Protection Program	62,761	1/1/97	3/31/05
16 Industrial Safety, Fire Protection, Infrastructure and Access	19,971	1/1/97	3/31/05
17 Integrated Monitoring System	6,098	8/1/97	3/31/05
18 Integrated Database	8,204	8/1/97	7/26/05
19 Fuel Containing Materials Removal & Waste Management Strategy & Study	3,364	8/1/97	7/13/01
20 Fuel-Containing Material Removal Technology Development	9,446	8/1/97	5/14/01
21 Safe Confinement Strategy	1,417	6/2/97	12/8/99
22 Implementation of Safe Confinement to Support Deconstruction and Fuel Containing Material Removal	258,609	7/1/99	7/27/05

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