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Improving Radiation Worker Safety at the Chornobyl Shelter

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INTRODUCTION

On 26 April 1986 the Unit 4 reactor at the Chornobyl[1] Nuclear Power Plant was destroyed as a result of a prompt critical nuclear excursion and subsequent steam and hydrogen explosions. The reactor was completely destroyed, as was much of the surrounding building. Nuclear fuel and core materials, including the graphite moderator, were directly exposed to the environment. Approximately 4% of the reactor's nuclear fuel was directly discharged to the environment as the result of the explosion. Because of decay heat from the nuclear fuel, much of the graphite moderator burned, resulting in a plume of radioactive gas and particulates that were carried as high as 10 km. The most recent reassessments of the release from this accident estimate that a total of 11×10^{18} Bq were released (1). This includes 100% of the noble gases, 60% of the ^{131}I, and 30% of the ^{137}Cs in the core inventory. Most of the uranium dioxide fuel that was not discharged from the core melted and combined with sand, concrete, and other materials in or near the reactor. This mixture formed lava that flowed into lower compartments and spaces beneath the reactor shaft. The graphite fire lasted until 10 May 1986.

In the six months following the accident an enclosure (i.e., Shelter[2]) was constructed over the remains of the reactor building and the destroyed reactor. Because of the severe radiological conditions much of the structure consisted of prefabricated sections that were placed on or above remaining portions of the building. It was not possible to conduct a detailed assessment of the structural integrity of many of the original walls and beams. Construction options were severely limited and many components were laid in place and held by friction only. Some prefabricated components never fitted together properly. In the 14-year history of the Shelter some settling of the underlying rubble has resulted in the shifting of some structural members and walls. As of 1996 the area of open spaces in the walls amounted to more than 100 m^2. These openings allow rain, snow, and wind to enter the structure. There is no engineered ventilation system or other environmental control except for a spray system that is operated for dust control (2).

The lava fuel containing masses (LFCM) that were formed in the 1986 accident have cooled significantly. Water has intruded into many of the areas containing the LFCM. In this high radiation environment water has reacted with the LFCM to produce a complex series of compounds. These previously monolithic LFCM are disintegrating into small particles and increasing the inventory of radioactive dust inside the Shelter. The dust inventory presents a potential radiological hazard to workers inside the Shelter. It is also the major source term for a release associated with a major structural failure or collapse of the Shelter.

In early 1996 the G-7 countries[3] entered into an agreement with the government of Ukraine to close the remaining units at the Chornobyl Nuclear Power Station and to transform the existing Shelter over Unit 4 into an environmentally safe system. All of the parties involved in this agreement recognized that the radiological and industrial safety programs and systems in place at the Chornobyl Shelter were inadequate to support the large-scale efforts that would be needed to accomplish a project that was projected to require eight to ten years at an estimated cost in excess of $750,000,000 US.

In May 1996 a team from the U.S. Department of Energy's Pacific Northwest National Laboratory (PNNL) traveled to Chornobyl and met with the staff to identify the highest priorities in upgrading the radiological protection program (3). As a result of the May 1996 meeting and followup discussions, both sides concluded that substantial improvements were needed in the following areas:

- External personnel dosimetry
- Internal personnel dose assessment
- Training of radiation workers and radiological protection personnel
- Radiological work planning and organization
- Engineered controls for contamination and airborne radioactivity control
- Fixed and portable radiological instrumentation

Because of the inherent difficulties in providing technical and warranty support to a remote location such as Chornobyl, both sides agreed that equipment and systems provided for use at the Shelter be limited to those that were commercially available and had been successfully deployed at least one other nuclear site of

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[1] In this paper the authors use the Ukrainian transliteration "Chornobyl" instead of the Russian "Chernobyl."
[2] The Russian and Ukrainian term for "shelter" ("Ukritie") is sometimes translated as "sarcophagus."
[3] The G-7 countries include the United States of America, the United Kingdom, Canada, France, Germany, Italy, and Japan.

similar size. Between May 1996 and December 1999 PNNL staff worked to address these needs. As a result, the capabilities of the Radiation Protection Department at the Chornobyl Shelter have improved substantially.

EXTERNAL PERSONNEL DOSIMETRY

PRIMARY EXTERNAL DOSIMETER

The personnel dosimeter originally used at the Chornobyl Shelter is a 3-element aluminum oxide (Al_2O_3) thermoluminescent dosimeter (TLD) of Soviet design and manufacture. All three elements are designed to measure deep dose. No record monitoring for shallow dose or dose to the lens of the eye was provided. The secondary dosimeter was an indirect-reading dosimeter. With this configuration, workers had no indication of accumulated dose during an entry. This placed excessive reliance on timekeepers and continuous coverage by radiation protection technicians, leaving workers unprepared to deal with unplanned or rapidly changing dose rates. Replacements for both the primary and secondary dosimeter systems were necessary.

PNNL is responsible for providing personnel dosimetry services for the U.S. Department of Energy's (DOE) Hanford Site. The Hanford site includes deactivated plutonium production reactors, nuclear fuel reprocessing facilities, high-level waste management facilities, plutonium and uranium facilities, and a variety of research laboratories. Between _____ and ____, PNNL undertook a systematic study and procurement process to upgrade its primary dosimeter to meet the requirements of the DOE's Laboratory Accreditation Program (DOELAP) for external personnel dosimetry (4). It was necessary for the upgraded Hanford dosimeter to accurately monitor personnel doses in a variety of situations including high-energy beta environments. Following a technical review by both PNNL and Chornobyl Shelter staff, it was determined that the specifications used for procurement of the upgraded Hanford dosimeter would be adequate to meet the monitoring needs at the Chornobyl Shelter.

In 1997 PNNL issued a Request for Proposals using essentially the same specifications as used for procurement of the upgraded Hanford dosimeter. After a careful evaluation of the proposals received, the model ______ Harshaw-Bicron[4] TLD system was selected. To assure the highest degree of reliability, two Model 6600 readers were selected. While a single Model 8800 reader would have been adequate, the staff decided to provide two systems so that processing could continue in the event of a failure of one of the readers. The system was also designed such that it could support not only the Chornobyl Shelter, but could easily be scaled-up to support dosimetry services for the entire Chornobyl site in anticipation of future decontamination and decommissioning activities.

SECONDARY PERSONNEL DOSIMETER

The benefit and need for a secondary dosimeter that provided real-time indication of accumulated dose, dose rate, and alarms on accumulated dose and dose rate was obvious to both sides from the outset of the project. The existing secondary dosimeter was an indirect-reading ionization chamber that did not workers any indication of accumulated dose during entries. Radiation protection personnel read the secondary dosimeters and the results manually entered into logbooks maintained at the access control point inside the Shelter. Manual recordkeeping further complicated efficient management of worker doses and good radiological work planning.

Both sides agreed that the new secondary personnel dosimeter would need to be combined with an access control and radiological records system. In order to meet cost and schedule constraints, it was decided that the secondary dosimeter must be a readily available commercially proven system that had been successfully integrated into the radiological protection program of a facility with a workforce of similar size to that expected at the Shelter.

PNNL has extensive experience in the testing of electronic secondary dosimetry systems, having performed extensive evaluations for the U.S. Nuclear Regulatory Commission[5] ***(ref)*** and the U.S. Department of Energy contractors under the Hanford Instrument Evaluation Project ***(ref)***. Activities at Hanford involve a wide variety of radiological conditions often complicated by extreme environmental factors (e.g., temperature). Since many of the radiological and environmental conditions within the Shelter were of a similar nature, both sides agreed that the technical specifications used for the Hanford secondary dosimeter were appropriate for application to the Shelter. Using this specification, PNNL procured 500 SAIC model PD-3 electronic dosimeters for use by the general work force.

The model PD-3 dosimeter provides real-time indication of dose rate and accumulated dose either in either SI or historical units and includes alarms for both accumulated dose and dose rate. The detector consists of an energy-compensated GM tube. The alarm setpoints can be programmed using an inductively coupled

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[4] The mention of specific brand names does not constitute an endorsement by the U.S. Department of Energy, the Pacific Northwest National Laboratory, or Battelle.

[5] The mention of specific brand names does not constitute an endorsement by the U.S. Nuclear Regulatory Commission.

docking station. This same docking station provides the interface to input data into the access control and radiological records systems.

Both sides also recognized that there were some situations involving high dose rates or the potential for rapidly changing conditions where real-time secondary dosimetry would be necessary. Using specifications developed for similar activities at Hanford, PNNL procured 25 of the SAIC model PD-4 electronic dosimeters. This model combines the features of the PD-3 coupled with a low-power radio transmitter to relay data to a control station. The PD-4 also includes a wiring harness that allows individual extremity monitors to be included if desired. The extremity monitors consist of small uncompensated GM tubes in a protective capsule that can be easily decontaminated if necessary.

INTERNAL PERSONNEL DOSE ASSESSMENT

Existing protocols for internal dose assessment involved the use of whole body counting for ^{137}Cs as the sole basis for determining and evaluating potential intakes of radioactive material

TRAINING OF RADIATION WORKERS AND RADIOLOGICAL PROTECTION PERSONNEL

RADIOLOGICAL WORK PLANNING AND ORGANIZATION

ENGINEERED CONTROLS FOR CONTAMINATION AND AIRBORNE RADIOACTIVITY CONTROL

FIXED AND PORTABLE RADIOLOGICAL INSTRUMENTATION

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