THE WASTE ISOLATION PILOT PLANT: AN OPERATING REPOSITORY SITE WITH UNIQUE OPPORTUNITIES FOR INTERNATIONAL RESEARCH AND TRAINING

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ABSTRACT

In October 2001, the International Atomic Energy Agency (IAEA) designated specific underground research facilities (URFs) as International Centers of Excellence. One of these three is the Waste Isolation Pilot Plant (WIPP) underground research laboratory (URL), which is managed by the United States (U.S.) Department of Energy (DOE) Carlsbad Field Office (CBFO). These URFs, which are in different geological media, i.e., clay, crystalline/igneous rocks, and rock salt, are available to the international radioactive waste management community through the IAEA "Network of Centers of Excellence on **T**raining in and **D**emonstration of **W**aste Disposal Technologies in Underground Research Facilities"(the TDW Network). The WIPP site also hosts an *operating repository* for safe disposal of long-lived, transuranic radioactive waste (TRUW). Both the URL and the repository are located approximately 650 meters (m) below the ground surface in a 250-million-year-old *bedded-salt* formation. The unique benefits offered by collaborations with the CBFO TDW Network Team include access to:

1. An existing URL that will remain *in operation* in support of mandatory, periodic recertifications of the WIPP repository, a global first-of-its-kind URF, *for at least another 30 years*.
2. A comprehensive, *regulator-reviewed* database and state-of-the-art conceptual and numerical process and total systems analysis (TSPA) models for a deep geological repository for safe disposal of long-lived radioactive wastes/materials (LLRMs).
3. Cradle-to-the-grave experience in the *successful* siting, designing, developing, certifying/permitting, and operating of a LLRM repository.
4. An existing, safely operating national system for safe deep geological disposal of LLRMs for *hands-on training and joint research and development (R&D) in all aspects of radioactive waste management and disposal*, including waste characterization and shipment.

INTRODUCTION

The DOE is committed to promoting an effective nuclear-safety culture worldwide and to affirming the importance of international cooperation in enhancing the safety of LLRM management through bilateral and multilateral mechanisms. In this spirit, the CBFO has made the WIPP URL (Fig. 1) and other CBFO-managed facilities and resources in New Mexico available to the international radioactive waste management community through the TDW Network. The TDW Network presently includes the following core URFs in different geological host media:

- The Hades URL at Mol, Belgium, in clay;
- The Lac du Bonnet URL at Pinawa, Manitoba, Canada, in granitic/igneous rocks; and
- The URL at the WIPP site, New Mexico, USA, in rock salt.

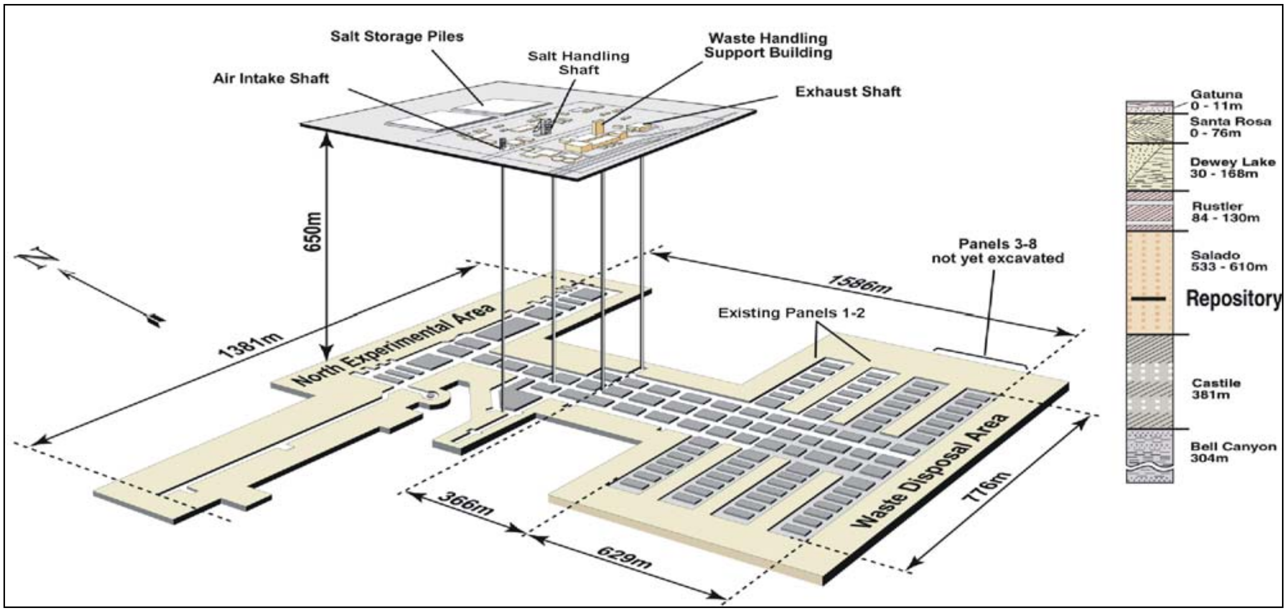

Fig. 1.Schematic illustration of surface and subsurface facilities (left) and the stratigraphic column (right) at the WIPP site.

The IAEA's primary objectives for the TDW Network are to:

- Supplement national efforts and promote public confidence in deep geological disposal of LLRMs;
- Contribute to the resolution of key scientific and technical issues; and
- Encourage the transfer and preservation of knowledge and technologies.

To meet these objectives and other potential needs of the TDW Network, the CBFO has established a TDW Network Team chaired by Mr. Mark Matthews of the CBFO (mark.matthews@wipp.ws) and the following four CBFO contractors:

1. Dr. Frank Hansen (fdhanse@sandia.gov) of Sandia National Laboratories (SNL). SNL has been the Science Advisor for the WIPP project since 1975. SNL developed the conceptual models for successful performance assessment (PA) calculations, completed a suite of large-scale thermo-mechanical in-situ geomechanics experiments, designed the engineered barrier system (EBS) and provided much of the information supporting the successful 1998 certification of the WIPP TRUW repository.
2. Dr. Jim Conca (jconca@lanl.gov) of Los Alamos National Laboratory (LANL). LANL conducted and reported on the actinide-related R&D supporting the successful 1998 certification of the WIPP TRUW repository and was the first shipper of TRUW to WIPP. LANL continues to serve the CBFO in these areas as well as in supporting the on-site characterization of TRUW.
3. Mr. Dennis Hofer (dennis.hofer@wipp.ws) of Westinghouse TRU Solutions LLC. (WTS). WTS has been the Management and Operations (M&O) Contractor for the WIPP project since 1978. WTS designed, developed, and maintains/operates all surface and subsurface facilities at the WIPP site, including all underground test locations, and compiled the required documentation in support of the favorable 1998 certification decision (1) and pending recertifications of the WIPP TRUW repository.
4. Mr. Leif Eriksson (leif@graminc.com) of GRAM, Inc., (GRAM), who has served as the CBFO International Programs Advisor since 1994. GRAM has provided WIPP software quality assurance (QA) and PA modeling support to SNL for more than 10 years.

The two primary objectives in this paper are to:

1. Foster discussions of CBFO activities that may be of interest and benefit to other organizations.
2. Establish strategic partnerships and collaborations enabling other organizations to draw upon the resources and facilities available through the CBFO TDW Network Team at the WIPP site and elsewhere in New Mexico.

To this end, this paper provides an overview of *past* activities of potential interest the international radioactive waste management community through the TDW Network Team. To place the CBFO missions in the appropriate national perspective, background information on the legal and regulatory framework for safe disposal of LLRMs in the USA precedes the description of past CBFO activities. For global perspective, particular emphasis is given below to the suite of *in situ* tests conducted in the WIPP URL between 1983 and 1995. These tests were designed to establish the suitability of rock salt to contain and isolate TRUW and high-level radioactive waste. Detailed information on past CBFO activities is available in the 1996 WIPP Compliance Certification Application (CCA). (1) In addition, the CBFO has compiled the "Prospectus on Waste Management and Repository Development with the U.S. Department of Energy Carlsbad Field Office", which provides an overview of past, current, and planned CBFO activities that is periodically updated. (2) Following the background section is an overview of potential benefits of collaborating with the CBFO TDW Network Team. A summary of conclusions concludes the main text. References indicated by numbers in parenthesis in the text (1-16) are listed after the main text, and terms deemed to be particularly important are highlighted in *italics* throughout the text.

BACKGROUND

The search for safe, disposition solutions for LLRMs began in the early 1950s. During the past 20 years, the internationally favored LLRM-disposition solution has been deep geological disposal. In addition, during the past ten years, many national and international organizations have expressed interest in augmenting deep geological disposal with an option to recover the emplaced LLRMs at a later date. Despite significant international efforts toward repository development, at the end of the year 2001, *the CBFO's WIPP TRUW repository is the world's only operating deep geological repository for LLRMs.* Another unique aspect of the WIPP disposal concept is that it validates the feasibility of the fundamental concept for deep geological disposal of LLRMs. In other words, WIPP provides the proof of principle that the characteristics of an appropriately selected geologic setting can provide the required post-closure containment and isolation of the LLRMs emplaced in the repository. The engineered barrier systems (EBSs) used for the TRUW to be disposed in the WIPP repository are designed to ensure the health and safety of workers and the public during waste storage, characterization, transportation, handling, and emplacement. In addition, the 1996 WIPP CCA (1) included a feasibility analysis of post-closure retrieval of the emplaced TRUW that was reviewed and approved by the U.S. Environmental Protection Agency (EPA). (3)

As demonstrated at the WIPP site, URLs play a substantial role in developing and demonstrating advanced radioactive waste disposal technologies and are, thus, a significant step to the ultimate construction and operation of full-scale geologic repositories for safe disposal of LLRM. However, the siting and development of a deep-seated URL in any given geologic medium require both considerable financial resources and specific scientific and engineering knowledge. For example, the siting, development, and opening of the WIPP repository required 24 years and 2 billion U.S. dollars. Hence, the ability of nations with small nuclear energy programs and/or nuclear waste volumes (SNPs) to develop URLs and repositories is limited. Furthermore, the time required by an SNP to develop and implement a successful repository program might be longer than that required at the WIPP site. Therefore, in the year 2001, the CBFO provided the WIPP URL and other CBFO-managed facilities and

resources in New Mexico to the international radioactive waste management community through the IAEA's TDW Network.
In accordance with the objectives stated by the IAEA for the TDW Network, summarized below under separate headings are the following items:

1. The Legal and Regulatory Frameworks for LLRM in the USA, including WIPP waste types and amounts, and the capacity and dimensions of the WIPP Disposal System.
2. The Evolution of the WIPP Site.
3. The WIPP Site Geology, including descriptions of important formations and related test results.
4. The 1983-1995 WIPP URL *In-Situ* Test Program.

The primary intent of these descriptions is to facilitate a basic understanding of the CBFO mission, conditions at the WIPP site, and the broad-range of challenges successfully resolved by the CBFO TDW Network Team to date. A few major challenges currently facing the CBFO are also described to demonstrate that:

- Existing facilities and infrastructure at the WIPP site will remain operational at least until the year 2034; and
- The CBFO intends to maintain an active R&D program to support pending re-certifications and to advance and incorporate advancing repository sciences.

The Legal and Regulatory Frameworks for LLRM Disposal in the USA

According to current U.S. laws (4-6), all LLRMs generated by civilian- and defense-related activities must be disposed in deep geological repositories. These laws also direct the DOE to site, develop, operate, and close the required repositories in compliance with applicable laws and regulations. To meet these statutory responsibilities, the DOE has established the following two essentially autonomous national programs/entities: the CBFO; and the Office of Civilian Radioactive Waste Management (OCRWM):

1. The CBFO `s mission it is to:
   (a) maintain and improve the national infrastructure required for safe characterization and transportation of up to 175,584 m^3 of TRUW[a] from the nation's 23 TRUW-generator and -storage sites to the WIPP site (Fig. 2);
   (b) maintain and improve the infrastructure required for safe disposal of the nation's TRUW at the WIPP site; and
   (c) provide the WIPP URL (Fig. 1) and related infrastructure to other organizations and institutions looking for training and R&D opportunities.

2. The OCRWM`s present mission is to:
   (a) establish the suitability and, if found suitable, develop and safely operate a deep geological repository for disposal of up to 70,000 metric tons of the nation's *civilian- and defense-generated* spent nuclear fuel (SNF) and HLW at the Yucca Mountain *candidate* site in Nevada; and
   (b) advise the U.S. Congress between January 1, 2007 and January 1, 2010 on the need for a *second* SNF/HLW repository.

Only the CBFO mission, which includes the National TRU Program (NTP), is addressed in this paper. The NTP is administered by the CBFO to achieve the following goals:

- Regulatory compliance among the nation's 23 TRUW-generator and -storage sites;
- Reducing risk while maximizing rate of TRUW disposal;
- Reducing mortgage costs by closing TRUW-generator and -storage sites as soon as possible; and
- Using the WIPP effectively by coordinating TRUW shipments with the TRUW-handling and -disposal capacities at the WIPP site.

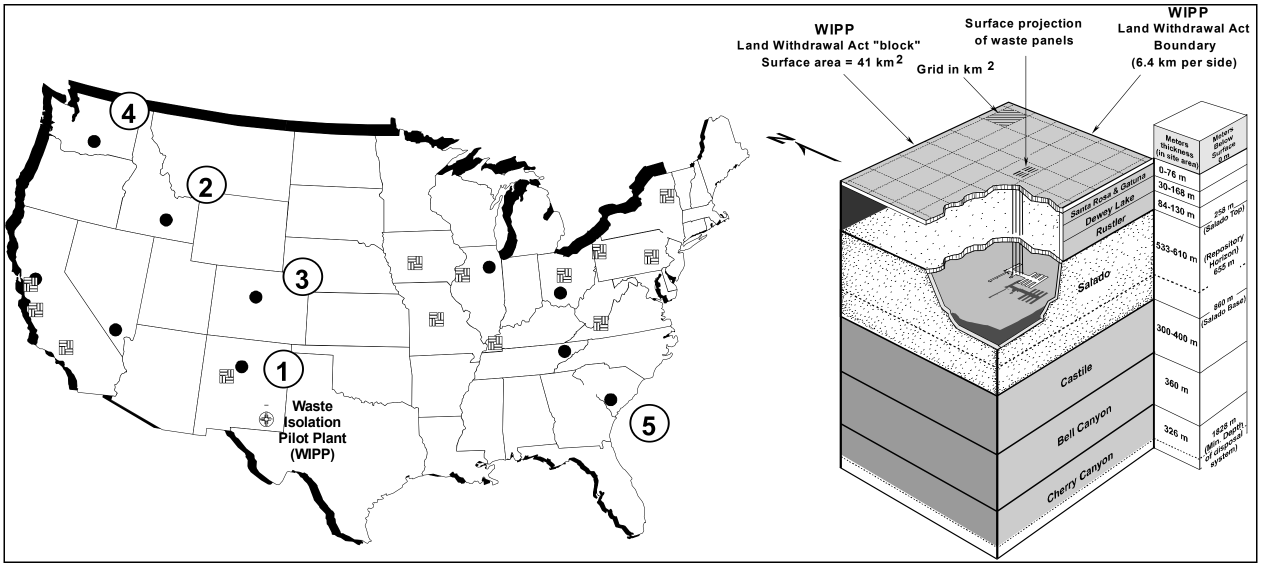

Fig. 2. The U.S. map (left) shows locations of the WIPP and the nation's 23 TRUW generator and storage sites (large-quantity sites are indicated by filled circles, small-quantity sites are indicated by squares, and sites numbered 1-5 have shipped TRUW to WIPP at the end of the year 2001). The schematic (right) shows the $41 km^2$,1.83-km-deep WIPP Disposal System and its main stratigraphic units.

The WIPP Land Withdrawal Act of 1992 (LWA) (4) set aside and restricted from public use the 6.4 km by 6.4 km surface area at the WIPP site to be used for the expressed purpose of the development of a TRUW repository. A separate agreement with the State of New Mexico limits the depth of the WIPP disposal System to 1.83 km (8). The WIPP site is located in a sparsely populated area of semiarid rangeland and fewer than 30 permanent residents live within a 16-km radius of the WIPP site. The nearest major population center is Carlsbad, which is home to approximately 27,000 residents and located approximately 42 km west of the WIPP site.

One unique aspect of the WIPP repository is the dual legal and regulatory frameworks that have to be complied with before disposal operations may commence, because the TRUW destined for the WIPP site may contain both regulated radioactive and hazardous constituents. The management and disposal of the regulated radioactive constituents are governed by the LWA (4) and related regulations. (9, 10) The management and disposal of the regulated hazardous constituents are governed by the Resource Conservation and Recovery Act of 1976 (RCRA) (11) and related regulations. Another unique aspect is the need to conduct two different types of post-closure safety analysis for the radionuclide inventory in the WIPP repository. (9) One analysis pertains to a repository only affected by reasonable natural events, also referred to as the *undisturbed case*. This analysis projects the maximum annual radiation dose to a member of the general public living at the most exposed location at the boundary between the WIPP Disposal System (Fig. 2) and the rest of the Earth, also referred to as *the accessible environment*. The other analysis pertains to a repository affected by both reasonable natural events and human intrusions with a probability of occurrence greater than one chance in 10,000 during 10,000 years (i.e., 10^{-8}). This analysis projects the cumulative amount of radionuclide releases reaching the accessible environment through the "intrusion pathway" and any other pathway.

The Evolution of the WIPP Site

The idea of siting a deep geological repository for safe disposal of LLRMs in New Mexico was conceived in 1971 by the local communities. (12) In 1975, SNL commenced surface-based site-characterization activities at the WIPP site that were augmented by laboratory tests and conceptual and mathematical/numerical model developments and implementations. In 1981, the construction of shafts, the URL, and a portion (Panel 1) of the repository began (Fig. 1). Between 1983 and 1995, the WIPP URL hosted a variety of large-scale and small-scale *in-situ* tests. (13) The primary objective of these tests, which are summarized below under separate heading, was to verify that rock salt was a suitable host rock for safe disposal of TRUW and *defense-generated* HLW (DHLW). This verification process actually began in 1975 with surface- and laboratory-based site-characterization activities, and the design and conduct of tests supporting the development of conceptual and mathematical/numerical process and TSPA models.

By the end of 1988, the comprehensive suite of surface- and URL-based *in-situ* tests conducted at the WIPP site had reached the point where SNL and the DOE believed that all geosciences information required for demonstrating that the WIPP site was suitable for hosting a very safe LLRM repository had been acquired. However, in 1987, a portion of the regulatory framework required for this demonstration had been successfully challenged in court, which delayed the opening of the WIPP TRUW repository. The three court-remanded aspects of the vacated regulation were repromulgated in December 1993. (9) In February 1996, criteria for compliance with the regulation were promulgated, (10) completing the regulatory framework required by the LWA for the development and operation of a deep geological repository for LLRMs (SNF, HLW, and/or TRUW) at the WIPP site. However, the LWA restricted the DOE to only consider/use the WIPP site/repository for safe disposal of TRUW and directed the DOE to recertify the WIPP TRUW repository with the EPA at least every fifth year after the commencement of TRUW disposal.

As shown in Figs. 1 and 3, the baseline repository layout comprises eight panels; each hosting seven disposal rooms. Each room is 4-m high, 10-m wide, and 91-m long. As shown in Fig. 2, the horizontal projection of the WIPP site is 41 square km (km^2), while the horizontal projection, i.e., "footprint", of the repository is approximately 0.5 km^2. The shortest lateral distance between the repository perimeter and the accessible environment (Fig. 2) is 2.4 km. At the end of the year 2001, only Panels 1 and 2 had been excavated and only Panel 1 had been used for disposal. Due to the rheological (creep) characteristics of rock salt, additional panels will be excavated sequentially as disposal demands arise in order to minimize ground-control requirements and cost.

The current disposal scheme is to stack contact-handled (CH)-TRUW[a] contained in 208-liter drums and larger standard waste boxes (SWBs) in the disposal rooms and to place remote-handled (RH) TRUW[a] containers in horizontal holes in the walls between the disposal rooms. Bags containing granulated magnesium oxide (MgO) are placed on top of the stacked CH-TRUW containers and in a portion of the void space between the walls and the CH-TRUW containers. The primary purpose of the MgO is to maintain stable chemical conditions that minimize actinide solubility in the disposal rooms during the 10,000-year regulatory period. Actinide solubility is an important consideration to the safe long-term performance of the WIPP repository because all TRUW is considered contained in "short-lived" containers. The MgO has other potential benefits, such as brine absorption.

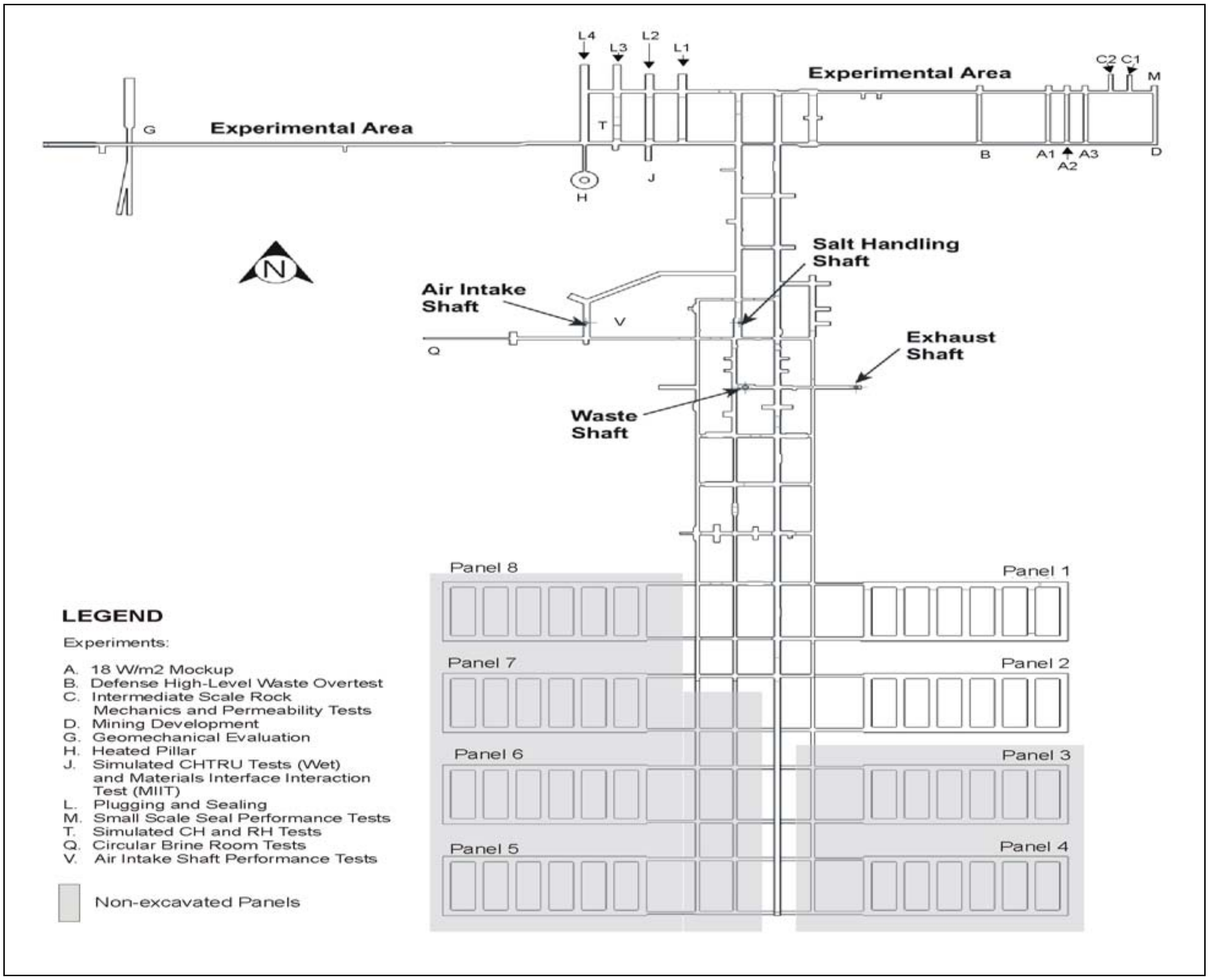

Fig. 3.Schematic illustration of the layout of WIPP URL and *in-situ* test locations.

In October 1996, after active engagement in a three-year public-participation/interaction process, the DOE submitted the WIPP CCA (1) to the EPA. The comprehensive safety and performance assessments conducted in support of the WIPP CCA showed that:

- The maximum, post-closure annual dose to a member of the public would be less than three percent (%) of the EPA’s dose limit and less than 0.15 % of the average natural background radiation in the USA; and
- The cumulative amount of radionuclide releases during the 10,000-year regulatory period would be less than 10% of the very stringent regulatory limits defined by the EPA even if the post-closure integrity of the WIPP TRUW repository was breached by multiple borehole intrusions. (1)

In May 1998, after a rigorous review process, the EPA announced that the TRUW repository proposed by the DOE at the WIPP site complied with all applicable LLRM-disposal regulations. (3) On March 26, 1999, the DOE opened the WIPP TRUW repository, receiving its first shipment of CH-TRUW from LANL (Fig. 2).

On October 27, 1999, the DOE received the RCRA Part B Permit required for disposal of mixed-TRUW[a] at the WIPP site. (14) However, the permit contained conditions that stopped all disposal activities at the

WIPP site for four months. CH-TRUW disposal commenced again on March 9, 2000 and the first mixed-CH-TRUW shipment arrived to the WIPP site on September 9, 2000. At the end of the year 2001, nearly 500 shipments (over 12,000 drums) of non-mixed and mixed CH-TRUW had been safely received and disposed at the WIPP site.

The WIPP Site Geology

The geology at and adjacent to the WIPP site is described in great detail in the WIPP CCA. (1) A condensed description of the WIPP site geology is provided below. The emphasis is on the geologic setting of the WIPP Disposal System shown in Fig. 2. Furthermore, as indicated above, human intrusions may introduce radioactive isotopes into boreholes and the geologic formations located above the repository host rock (Fig. 4). It is therefore necessary to understand the hydrologic system and the transport processes in that system. Thus, this section focuses on hydrological characteristics governing the releases of radionuclides from the WIPP repository.

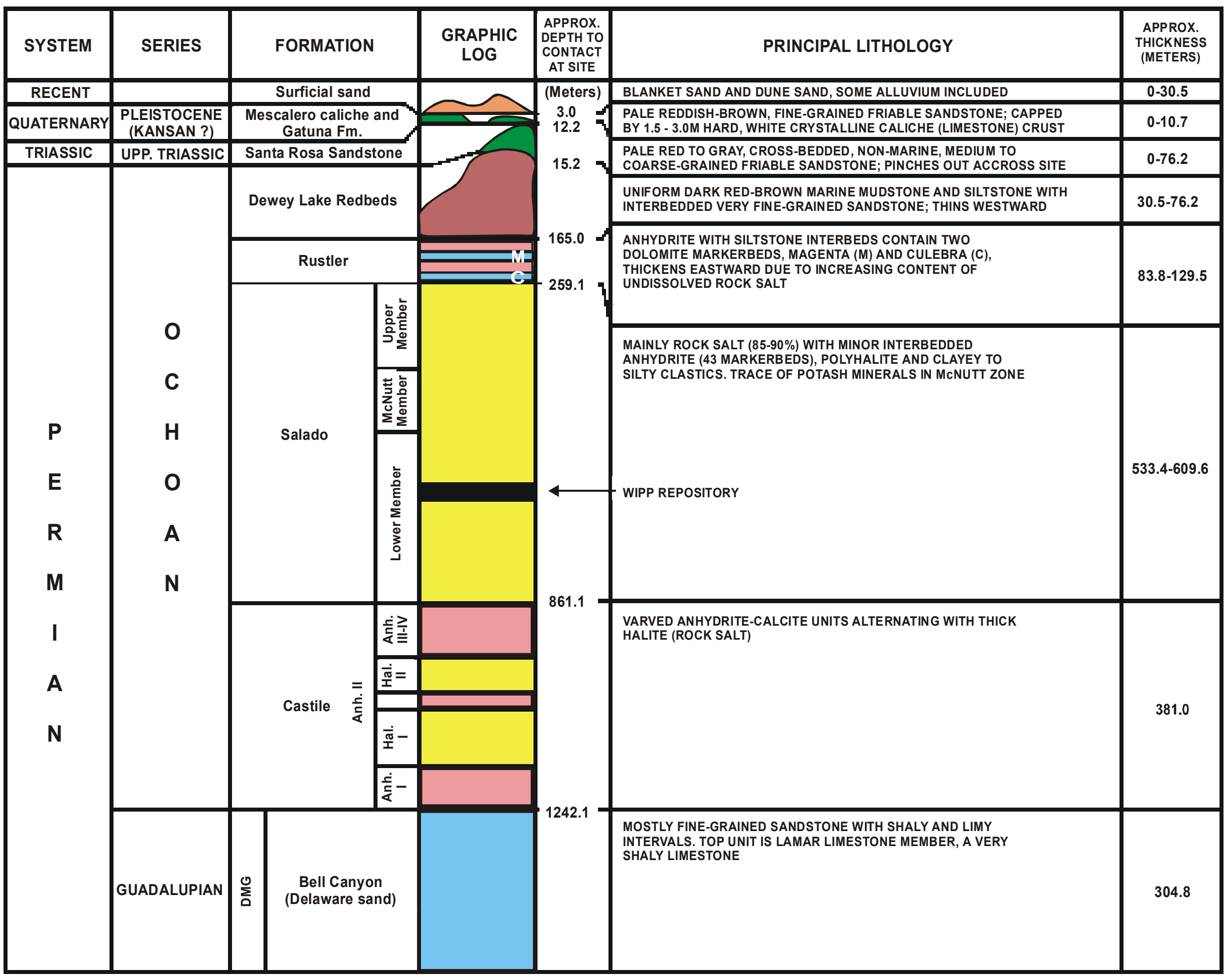

Fig. 4.Generalized stratigraphy at the WIPP site.

The WIPP site is located on an arid, generally flat plain covered with sand, caliche, and desert bushes in the southeastern portion of New Mexico. Geologically, the WIPP site is located in the Delaware Basin, which covers over 33,000 km^2 and is filled with sedimentary rocks to depths of 7,300 m. The stratigraphic column at the WIPP site comprises about 4,575 m of Paleozoic sedimentary rocks on top of the Precambrian basement. As illustrated in Fig. 4, the host rock for the WIPP repository is a bedded salt horizon in the 225-250-million-year-old, 600-m-thick Salado Formation (Salado). The top of the Salado is situated approximately 400 m below the ground surface, and the horizon for the WIPP URL and repository is located approximately 650 m below the ground surface. The Salado is overlain by the Rustler Formation (Rustler) and underlain by the Castile Formation (Castile).

As field studies progressed in the late 1970s, it became clear that the hydrologic system and the transport processes of the WIPP Disposal System were more complex than first anticipated. Hence, extensive pumping tests and large-scale, non-radioactive, chemical-tracer tests were conducted to clarify the hydrologic transport mechanisms involved. The focus of these tests was on the Culebra. Laboratory tests, not discussed here, were also useful in elucidating the transport behavior. Hydrologic studies were conducted in the salt beds despite their low permeability. These tests were performed to understand and quantify brine seepage into repository rooms. This seepage is one possible source of water that could interact with the waste and generate gas, an important aspect of long-term repository performance. The tests also provided permeability values for modeling the movement of gas and brine outward from the waste-disposal rooms.

More than 50 deep boreholes have been drilled from the surface and tested to assess and evaluate the hydrologic system at the WIPP site. These tests permitted determination of the transmissivity field over the site region and also identified the physical transport mechanisms. Initial studies examined the three most transmissive units overlying the Salado, but, ultimately, focussed on the Culebra. Test holes were subjected to slug tests and drawdown tests to obtain local estimates of Culebra transmissivities. Non-sorbing tracer tests were used to provide better definitions of the hydrologic system and its transport mechanisms. Multiple tracers injected in up to six satellite holes were detected through frequent sampling of the pumping well and laboratory analysis. Radioactive tracers were not employed due to their prohibition during site characterization. Hydrologic testing in the Culebra continues today using conventional electronic instrumentation to record water levels and pressure fluctuations.

Before 1986, the thick salt beds at WIPP were considered essentially dry and impermeable. The small amount of brine seepage noted on portions of the freshly mined surfaces is explained by the development of micro cracks and a large pore-pressure gradient in the salt, which drives the intergranular brine to the free surface. The very low permeability of the Salado salt could not be accurately assessed from the surface due to the special techniques and precision required. Furthermore, hydraulic testing in the Salado presented unique problems due to the very low permeabilities that exist in the salt. Pressure decay testing proved to be the most appropriate method to establish the salt permeability.

Twenty-two hydraulic tests have been performed in impure halite, and two in pure halite at the repository elevation. Tests were conducted in boreholes at depths ranging from 5 m to 50 m. Inclined holes were used to test the anhydrite interbeds above and below the waste emplacement horizon. Measurements were conducted in both the halite and the anhydrite interbeds. Both pressure build-up and pressure decay measurements were used to calculate the permeability. For studies in conjunction with brine seepage (Q-Room [Fig. 3]), emplaced resistivity grids tracked the movement of the brine through the disturbed rock zone (DRZ), from the walls into the floor of the experimental drift. These measurements were accompanied by pore-pressure gages that followed the changes in inter-crystalline brine pressure as the drift was excavated and the DRZ formed.

The 1983-1995 *In situ* Tests Conducted in the WIPP URL

Between 1983 and 1995, the WIPP URL was used to study the effects of both DHLW and TRUW emplacement in bedded salt. Fig. 3 shows the layout of the WIPP URL and repository, and the locations of the large-scale, *in-situ* tests conducted in the URL. Summarized below are descriptions of the following three main groups of *in-situ* tests conducted in the URL for establishing the effectiveness of containing and isolating LLRMs in a salt repository:

1. Thermal/Structural Interactions (TSI) Tests.
2. Plugging and Sealing (P&S) Tests.
3. Waste Package Performance (WPP) Tests.

Although a large number of laboratory-based tests were supplementing the larger-scale *in situ* field tests, the emphasis in this section is on the *in situ* field tests. Additional information is available in the WIPP CCA (1) and in other publications. (e.g., 2,13)

The purpose of the first group of tests listed above, the Thermal/Structural Interaction (TSI) Tests, was to develop and confirm predictive modeling and calculational techniques for design and performance assessment of bedded salt repositories. Predictive techniques are necessary to extrapolate geomechanical information developed from short-term data (one to ten years) to long-term behavior (100 to 10,000 years or longer). The TSI tests were designed to address: (1) the stability of the excavated rooms during repository operations and possible waste retrieval; and (2) long-term deformation of the disposal room. The following suite of TSI tests were conducted to address the mechanical behavior of rock salt as influenced by excavation effects, stress, and thermal loading and interactions induced by waste emplacement: (1) the HLW Mockup Tests (Mockup Tests); (2) the DHLW Overtest (Overtest); (3) the Geomechanical Evaluation Test; (4) the Heated Axisymmetric Pillar Test; (5) the Scale Effects Tests; and (6) the Ambient Temperature Tests. The locations (Fig. 3) and objectives of these were as follows:

- Eighteen *Mockup Tests* were conducted in Rooms A1, A2, and A3. The primary objectives of the Mockup Tests were to determine: (1) rates of salt creep and room closure; (2) effects of heat transfer to the host rock; (3) confirm predictive methods and techniques; and to demonstrate (4) the suitability of a reference HLW disposal room.
- The *Overtest*, conducted in Room B, was an accelerated version of the Mockup Tests. The primary objectives of the Overtest were to: (1) determine room closure rate and heat transfer at elevated temperatures; (2) confirm predictive techniques; and (3) evaluate long-term effects of heat and room closure. The Overtest used about four times the reference thermal load to drive the room to failure more quickly to provide additional information on the creep constitutive model verification and structural data on canister response and room-failure mechanisms.
- The *Geomechanical Evaluation Test*, shown as Room G, was designed to determine: (1) the effects of room geometry on the creep deformation of drifts for two-dimensional (2-D) analysis; (2) the validity/applicability of the theoretically developed models in predicting the response of different-sized openings; (3) the response of 3-D drift intersection and the validity of using 2-D modeling techniques; (4) the failure mode of a large volume of salt under high stress; (5) the techniques for developing underground drift designs; and (6) *in situ* stress by hydrofracturing techniques. However, only item (1) was completed due to funding restraints.
- The *Heated Axisymmetric Pillar Experiment Test*, conducted in Room H, was designed to determine: (1) the validity of the models and computer codes in predicting the response of heated rock-salt mass; (2) the behavior of room and pillar in response to (accelerated) creep; (3) the mechanical properties and failure modes of salt and other constituents in the testing envelope; (4) to compare actual 3-D response to 2-D models; and (5) to compare *in situ* data from laboratory-model pillar tests and from other salt mines to assist in model evaluation. After acquiring creep information on the pillar and room at ambient temperature for one year, the pillar was covered with an insulating blanket and heated with strip heaters to about 70^{o}C. This heating continued until one year before decommissioning to allow a one-year cool-down period. Ten years of active data were acquired from

this test. Installed instruments measured: (1) vertical and horizontal room closure; (2) deformation of the salt mass bordering the room; and (3) stresses in the rock mass bordering the room.

- The <u>*Scale Effects Tests*</u> were conducted in Rooms Q and C and designed to resolve the debate over whether the scale of excavations could be responsible for some of the discrepancies between observation and model calculations. Two cylindrical boreholes of different dimensions were instrumented and observed. One borehole, 30-m-long and about 1-m in diameter, was constructed between Rooms C-1 and C-2 after a pre-emplaced array of stress and extensometer gages was recording baseline data. The other test was conducted in conjunction with the 100-m-long, 3-m-diameter boring of Room Q and implemented primarily to conduct a large-scale brine-seepage test. Structural behavior of both test results was accurately predicted by the model, eliminating scale effects as a source of concern in the calculations.
- The <u>*Ambient Temperature Room Test*</u> was conducted in Room D. This room was the earliest room excavated in the experimental complex and was used to test gage-installation techniques and obtain rock-mechanics data at ambient temperature. Room D had the same geometry as the heated Room B and was, thus, a useful baseline against which to compare the accelerated creep experienced in Room B.

The primary objectives of the second group of tests listed above, the *Plugging and Sealing (P&S) Tests,* were to: (1) develop candidate materials and structural systems for long-term plug/seals at WIPP; (2) evaluate materials and emplacement techniques for adequate sealing of boreholes, shafts, and drifts; (3) develop assessment techniques for predicting long-term performance with field and full-sized tests; (4) evaluate host-rock permeability and other properties related to plug/seal interactions; (5) demonstrate plug/seal performance with field and full-sized *in situ* tests; and (6) develop a design basis and criteria for the plugs and seals at WIPP. Formation tests characterized permeability, gas flow, moisture transport and release, and Air Intake Shaft (AIS) performance. Seal-related tests included a plug test matrix, borehole plugs, small-scale seal performance (Room M), and backfill design and emplacement. The P&S Tests provided the technical basis for a defensible design for sealing the WIPP repository after decontamination and decommissioning (D&D). The long-term sealing strategy utilized the reconsolidation of crushed salt, eventually resulting in a seal that approaches the density, permeability, and strength of the intact salt. To assure isolation and prevent fluid intrusion in the time frame before crushed salt reconsolidation is completed, clay, concrete, and asphalt plugs supplement the primary salt plug. Testing involved both laboratory and intermediate-scale (m-diameter holes) *in situ* testing of these materials. Emplacement evaluations and fluid-flow studies provided guidance on the design of the WIPP seal system.

Although the present WIPP Disposal System does not rely upon the waste package for long-term radionuclide containment or isolation, the third group of tests listed above, the *Waste Package Performance (WPP) Tests*, were conducted in the WIPP URL to evaluate the short-term (5 to 50 years) integrity of the waste package for both CH- and RH-TRUW. Despite the "TRUW" classification of these tests, no radioactive materials or constituents were used or involved in the tests. The primary objectives of these tests were to: (1) assess the durability of waste packages in near-reference and overtest conditions; (2) determine confinement integrity of waste packages; (3) evaluate the effectiveness of engineered barriers for waste confinement; and (4) evaluate predictive models and techniques for assessing long-term performance. A secondary objective was to develop an understanding of the conditions that might be faced during the operational period of WIPP in the event that retrieval was required. Additionally, because bedded salt was still being considered for disposal of HLW in until the late 1980s, *in situ* experiments were conducted in the WIPP URL to evaluate possible HLW canister materials and to examine leaching of candidate glass waste forms of several other nations. However, interest and funding for HLW experiments at the WIPP site diminished in 1987 when the U.S. focused its HLW-repository-development efforts on the Yucca Mountain site (tuff), Nevada, and abandoned the candidate salt repository site in Deaf Smith County, Texas. (7)

Rock-mechanics testing on core, backfill compaction, gas generation, and chemical studies of MgO were more efficiently and cost effectively carried out in existing off-site test facilities and laboratories. In general, where the scale and reality of underground testing did not add to the understanding of and confidence in the process being evaluated, the tests were done above ground, where the experimental parameters were more easily controlled. Furthermore, restrictions at the WIPP prior to operation required that experiments with radioactive isotopes and radioactive waste be conducted off site. Consequently, batch sorption and flow through retardation studies with the actinide isotopes were conducted at several national laboratory locations such as SNL and LANL.

POTENTIAL BENEFITS OF COLLABORATING WITH THE CBFO TDW NETWORK TEAM

The CBFO continues to support a focused R&D program. This program relies upon state-of-the-art scientific and engineering resources for the continued design and development of the data and conceptual and numerical models, which, along with the continued safe operation of WIPP, are necessary to:

1. Demonstrate continued compliance with the certification decision and applicable radioactive waste disposal regulations.
2. Respond to external recommendations and concerns.

The National Academy of Sciences (NAS) and the New Mexico Environmental Evaluation Group (EEG) are two independent organizations that have monitored and commented on the WIPP program since 1978. To date, the NAS has issued ten major reports and several additional interim and letter reports, and the EEG has issued more than 80 far-reaching reports. Of particular importance to the CBFO's continued management of the WIPP site and the NTP are two reports issued during 2001 by the NAS' Committees on the WIPP and the Characterization of RH-TRUW, respectively. (15,16) The CBFO will respond to these reports by conducting the appropriate R&D and studies.

As part of its strategy to find programmatic benefit in international partnerships and collaborations, the CBFO also supports and hosts both radioactive-waste-management and non-radioactive-waste-management-related R&D activities at WIPP that promote the use of the local science community and national laboratories. For example, in 1999, several transparency-monitoring experiments were conducted in the WIPP URL and preliminary results were demonstrated at the DOE International Conference on Geologic Repositories. As a result of one of the sessions from this conference, there was a recommendation that WIPP should be developed as a test-bed for international collaborations on safeguards, security and transparency of geologic repository systems. Since then, WIPP has maintained transparency equipment and demonstrations in the underground and is anticipatory of international collaborations. The geologic setting at the WIPP site has elements that are true analogues to most other planned repositories that put WIPP in a unique position to serve as a test-bed for the development, testing and demonstration of repository transparency and technologies. In fact, WIPP's history is one of openness and scrutiny at local, state, national and international levels, and many activities at WIPP qualify as examples of transparency.

The CBFO's non-radioactive-waste-management R&D activities include two LANL astrophysics experiments. The first one tests ultra-low background neutron proportional counters to determine their sensitivity. These detectors are being used in the Canadian Sudbury Neutrino Observatory experiment. The second one tests solid-state dark-matter detectors in a low-radiation background environment to determine whether the WIPP provides a suitable environment to host a large-scale dark matter detector array. In addition, a collaboration of U.S. universities and researchers and international researchers has proposed an Ultimate Underground Nucleon Decay and Neutrino Observatory. This large undertaking requires several proof-of-concept engineering tests to demonstrate the feasibility of ground control, cavity design, and tank-structure design. The CBFO has also responded to a "Program Scoping Analysis Field

Data Request" for the Advanced Accelerator Applications program. The WIPP is one of five facilities selected for further study and Environmental Impact Statement preparation.

These activities, and the possibility of using the WIPP infrastructure (including the underground) for R&D and training, enhance the opportunity for international collaborations in Carlsbad. The CBFO plans to continue a vigorous international program that will serve as a focal point and forum for collecting, collating, exchanging, and developing information that supports the missions of both the CBFO and the international radioactive waste management community. This includes attending and hosting/co-hosting international workshops, conferences, and symposia. The CBFO and its main contractors will support collaborative activities with underground test beds and personnel. Office space, computer equipment, and staff support will be provided at the WIPP site and in Carlsbad. Hence, collaboration with the CBFO TDW Network Team provides a unique opportunity for other radioactive waste management organizations to (1) conduct underground state-of-the-art experiments in an existing, well-maintained URL and (2) train employees in the design and implementation of a broad range of waste-management activities*, including the safe operation of a deep geological repository*.

In addition, the 25 years of site characterization and 17 years of repository development activities preceding the 1999 opening of WIPP have resulted in extensive databases and interpretative capabilities among the members of the CBFO TDW Network Team. The experience gained to date also includes:

- Successful planning, designing, and implementing of site-characterization programs, which integrated state-of-the-art investigations, tests, and conceptual and numerical models;
- Successful demonstration of compliance with extremely stringent and prescriptive radioactive and hazardous waste disposal regulations, culminating in the 1998 *certification* (radioactive waste) and 1999 *permitting* (hazardous waste) of the WIPP repository; and
- Successful planning, designing, and implementing of public, scientific, regulatory, institutional, and political acceptance programs.

The applicability of this experience to other radioactive waste management programs is based on the recognition that:

- All sites considered or proposed for deep geological disposal of LLRMs must be characterized for basic geological, (geo)chemical, and hydrological properties;
- The magnitude and potential consequences of the temporal and spatial changes caused by the construction, operation, and closing of the repository must be evaluated;
- All deep geological repositories must implement tunnel and/or shaft seals and other engineered barriers to contain and isolate the emplaced LLRMs; and
- Most, if not all, candidate repository sites are evaluated in the context of formal risk, safety, or performance assessments over tens- and hundreds-of-thousands of years.

Radioactive waste management organizations that collaborate with the CBFO TDW Network Team can become familiar with successful conceptual and numerical models, repository development and operational approaches used at the WIPP site in a very timely and cost-effective manner. Effective international partnerships should advance the programmatic interests of all participants, though all participants need not have the same objectives or needs for the partnerships to be effective. Rather, participants may engage in an activity for many different reasons.

An important objective of the CBFO's participation in international programs is to enable project staff to keep abreast of technical, political, programmatic, and regulatory developments within the international radioactive waste management community. To date, the CBFO has benefited in the following ways from partnerships and collaborations with other radioactive waste management organizations, which in turn might similarly benefit other radioactive waste management organizations:

- Cost savings;
- Development of credible data and models;
- Increased confidence in facility reliability and its safety case;
- Refinement/simplification of management, testing, and operations procedures;
- Broader input into and critical review of experiments and analyses; and
- Advancement of scientific expertise in areas of mutual interest.

To that effect and in response to the recent NAS recommendations, (15,16) a particularly interesting joint-international test at WIPP would be to conduct an accelerated-room-scale test with objectives similar to that of the multi-national, European Union-sponsored Prototype Repository Test conducted at the Äspö hard-rock laboratory in Sweden. Such a test would also address additional, geologic-media-specific issues of both domestic, i.e., NAS, and international concern such as brine migration, gas generation, canister mobility, canister durability, instrument accuracy, reliability, and longevity, and canister-retrievability techniques.

SUMMARY OF CONCLUSIONS

The IAEA's sponsored TDW Network will enable other national radioactive waste management organizations to cost-effectively acquire information and participate in URL-based repository-science R&D in the following three different repository-host media:

1. Granitic/igneous rocks (the Lac du Bonnet URL, Canada).
2. Clay (the Hades URL, Belgium).
3. Rock salt (the WIPP URL, USA).

Of these three URLs, only the WIPP is co-located with an *operating* deep geologic repository for safe disposal of LLRMs. Hence, collaboration with the CBFO TDW Network Team provides a globally unique opportunity for prompt and cost-effective access to:

- Information and models that have been subjected to and *met* strict QA requirements and intense scrutiny by the public, state and national expert groups, national and international peer review groups, and ultimately, the regulators.
- Training in all aspects of URL and LLRM-repository development and operation, including the development and *implementation* of highly successful programs for (a) regulation-focused, TSPA-driven siting criteria and site-characterization programs, (b) regulatory applications, and (c) public interactions.
- The "cradle-to-grave" LLRM-disposal knowledge vested in the CBFO TDW Team, which also include hazardous waste disposal.

FOOTNOTES

[a] TRUW destined for WIPP must be defense-related/generated and contain at least 3,700 becquerels (Bq) of alpha emitting, transuranic (i.e., atomic weight/number greater than ^{92}uranium) isotopes with half-lives greater than 20 years, per gram of waste. However, the canister surface dose rate may not exceed 10 sieverts per hour (Sv/h). There are the following three general categories of TRUW: (1) contact-handled (CH), which has a maximum canister surface dose rate of 0.002 Sv/h, (2) remote-handled (RH), which has a canister surface dose rate between 0.002 Sv/h and 10 Sv/h; and (3) mixed, which

could be either CH-TRUW or RH-TRUW containing regulated, non-radioactive, hazardous constituents.

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