General Training On Methodologies For Geological Disposal in North America

*IAEA Network of Centers of Excellence*

# INTERNATIONAL TECHNICAL COOPERATION

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Office of Repository Development
Las Vegas, Nevada

## Geologic Repository Programs Worldwide

## INTERNATIONAL COOPERATION

**Benefits for R/W Management Programs**

- **An excellent, time-tested and proven method for building a scientific and technical program and training technical program staff for site characterization, performance assessment and repository engineering by leveraging efforts and costs through bilateral and international cooperative research and development programs.**

## FINANCIAL BENEFITS

- Leverage limited funds
- Realize savings on the costs of Research & Development (R&D)
- Eliminate some costs of R&D by transferring technology from foreign programs
- Reduce costs for other R&D efforts by sharing costs with one or more partners
- Share capital and operating costs for developing and operating surface and underground testing facilities


## TECHNICAL BENEFITS (1)

- Access to:
  - Unique foreign FACILITIES
  - Unique foreign-collected DATA SETS
  - Foreign SCIENTISTS & ENGINEERS
  - Foreign TECHNIQUES
  - Foreign EXPERIENCE
  - Foreign INSTRUMENTS
- Immediate Access to:
  - NEW DEVELOPMENTS


## TECHNICAL BENEFITS (2)

- Developing Program's managers, scientists, and engineers are provided with "Hands-On" experience
- Developing Program's scientists and engineers have their "Learning Curve" shortened significantly
- Developing Program receives direct "Transfer of Technology" from foreign programs and international partners
- Developing Program's scientists can use foreign and/or multinational facilities to research, develop, modify, and prototype-test experimental concepts, scientific instruments, techniques, and analyses for site characterization


## TECHNICAL BENEFITS (3)

- Foreign data sets can be used to develop, improve, test, and validate Programmatic conceptual and numeric models for geology, hydrology, geochemistry, source term, waste package, and biosphere for use in site selection, site suitability determination, and/or developing a license application



## However, Mature Nuclear Waste Programs, May Use International Cooperation To Seek Different Benefits

**Organization and History of USDOE International Cooperative Programs**



## Purpose of USDOE International Technical Programs

**Develop International Consensus on Approaches,Technologies, Instrumentation, and Robust Methodologies for Characterizing and Evaluating the Suitability of Deep Geologic Disposal**



## Early USDOE Technical Cooperative Programs

- **Stripa Project (Sweden): Granite, 1977-1991**
  **Development of instruments, techniques, and tests for evaluating proposed repository sites**
  - **Swedish - American Cooperative Agreement, 1977-1980**
  - **OECD/NEA International Stripa Project, 1980-1991**
- **DOE-BMFT (Germany): Salt formations, 1984-1988**
  **Exchanges of information, personnel, and technical studies**
- **DOE-NAGRA (Switzerland): Granite, 1986-1988**
  **Cooperative studies on fracture characterization methodologies, fracture hydrology, multi-phase flow and coupling of transport and geochemistry**
- **DOE-AECL (Canada): Granite, 1986-1988**
  **Development and testing of instruments and techniques, and development of tests to determine suitability of crystalline rocks**
  **Personnel exchange**



## The Beginning:

SWEDISH - AMERICAN COOPERATIVE AGREEMENT,1977 - 1980

- **Bilateral cooperative program of research and development (R&D) for geologic disposal of high level nuclear waste**
- **Studies conducted underground at the Stripa Iron Mine in central Sweden.**
- **Tests Consisted of:**
  - **Full scale and time scale heater tests**
  - **Hydrological studies**
  - ***In situ* stress measurements**
- **USDOE participant:**
  **Lawrence Berkeley Laboratory**



## OECD/NEA STRIPA PROJECT Phases 1, 2 & 3: 1980 - 1991


AECL


TVO


CEA


PNC


ENRESA


SKB


NAGRA

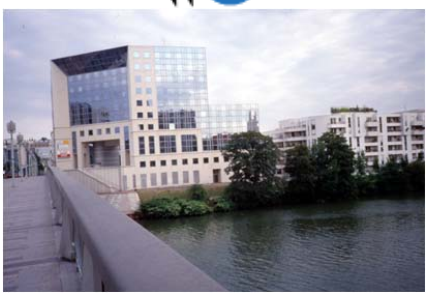

UKDoE


USDOE

OECD OCDE

## Nuclear Energy Agency (NEA)
## Radioactive Waste Management Committee - Paris, France

OECD OCDE





OECD OCDE

## OECD/NEA RWMC Members

Australia | Belgium | Canada | Czech Republic | Finland | France

Germany | Hungary | Italy | Japan | Korea | Nether-lands

Spain | Sweden | Switzer-land | United Kingdom | United States



## OECD/NEA STRIPA PROJECT Phase 1 (1980-1985)

- Developed borehole testing methods for determining hydrologic characteristics of fractured rock.
- Investigated the geochemistry of deep groundwaters.
- Tested *in situ* fracture migration to extend laboratory experiments on sorption and retardation of radionuclides.
- Investigated the suitability of bentonite clay buffers under simulated repository conditions.

OECD OCDE

## OECD/NEA STRIPA PROJECT Phase 2 (1983-1987)

- Developed borehole radar and borehole seismic methods to detect and characterize fracture zones.
- Conducted migration experiment to evaluate transport processes.
- Determined the suitability of bentonite clay to seal boreholes, shafts, and tunnels.
- Characterized the fracture system geometry, and permeability and porosity distributions.
- Determined geochemical origin and evolution of deep groundwaters and mechanisms of water-rock interaction.

OECD OCDE



## OECD/NEA STRIPA PROJECT Phase 3 (1986-1991)

- Conducted phased site characterization and validation experiment in fractured rock.
- Developed methods to improve quality of site assessment predictions:
  - High resolution directional borehole radar and borehole seismic techniques.
  - Developed three dimensional network flow model.
  - Investigated channeling in fracture systems.
- Investigated sealing of groundwater flow paths in fractured rock:
  - Survey of fracture sealing materials
  - Designed and conducted tests of long-term stability.
  - Field tests to develop/evaluate effective injection techniques.

OECD OCDE



## OECD Nuclear Energy Agency (NEA)

- All NEA radioactive waste activities are under the Radioactive Waste Management Committee (RWMC)
- Selected RWMC activities:
  - AMIGO: Modeling geologic features for Performance
  - Clay Club
  - EBS Project (with EC)
  - Features-Events-Processes (FEP) Database
  - Forum on Stakeholders Confidence (FSC)
  - Geosphere Stability
  - GEOTRAP (Radionuclide Transport in the Geosphere)
  - Integration Group for the Safety Case (IGSC)
  - INTRAVAL - HYDROCOIN - INTRACOIN - PSACOIN
  - Peer Reviews
  - Performance Assessment Advisory Group (PAAG)
  - Site Evaluation & Design of Experiments (SEDE)
  - Sorption Group
  - International Stripa Project
  - Thermochemical Data Base (TDB)

OECD OCDE

## OECD NUCLEAR ENERGY AGENCY

**Coordinating Group on Site Evaluation & Design of Experiments (SEDE)**

**US Delegation Helsinki, Finland 1991**



## OECD/NEA THERMOCHEMICAL DATA BASE

- Experts from OECD/NEA countries develop, compile, and review comprehensive, internationally recognized and peer reviewed thermochemical data for major components of radioactive waste:
  - **Inorganic U, Am, Tc, Np, Pu
  - *Inorganic Se
  - *Inorganic Ni
  - *Organic Ligands (Ox, Cit, EDTA, ISA) with U, Np, Pu, Am, Tc, Se, Ni, Zr
  - *Inorganic Zr
  - #To be chosen from: Th, Fe, Mo, Sn

  [ **Completed; *Planned 2004 completion; #Phase III ]
- Databases are developed at a fraction of the cost possible for a single nation alone.

OECD OCDE



## DOE Developed International Technical Cooperative Programs Under Specific Rules

- Should not replace nor duplicate mainstream DOE activities.
- DOE should never become dependent on international programs to meet internal programmatic milestones or deliverables.
- Activities were not designed nor intended to provide data directly for use in licensing.
- DOE would not require international partners to develop nor provide QA program.
- International activities were not designed to develop quality-affecting data.

## YMP International Programs Were Developed Under Following Rules

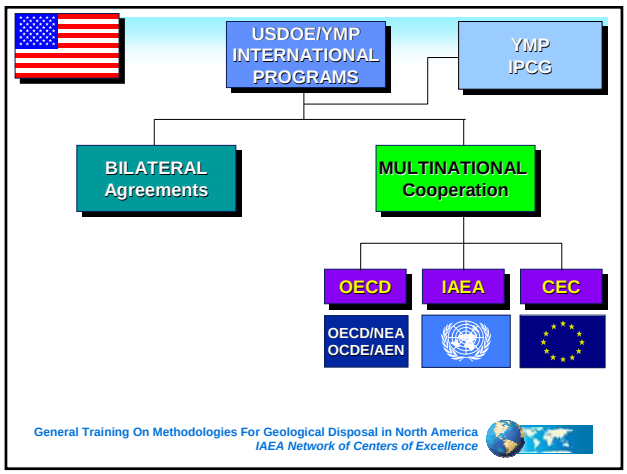
- All technical work must follow good scientific and engineering practice.
- All activities must support or enhance DOE activities:
  - Develop and/or prototype instruments and techniques
  - Provide "hands-on" experience for DOE investigators
  - Provide foreign-developed technical understanding, hardware, and facilities.


## Selected Issues Studied

- Ground Water Travel Time (GWTT)
- Fracture Flow Hydrology
- Multiphase (Unsaturated) Flow
- Waste Package / Source Term
- Radionuclide Migration / Retardation
- Near-field Effects:
  - Thermal / Hydrologic / Geochemical
  - Man-Made (Sealing) Materials
  - Excavation Disturbed Zone (EDZ)
- Instrumentation
- Natural Analogues


## DOE International Tasks: 1990-1995

- Cigar Lake Natural Analogue
- Fundamental Materials Investigations (Concretes)
- Hydrochemical Tool: Laboratory & Field Testing
- *In-Situ* Stress Determination
- Large Block Tracer Test - Retardation Models
- Multiple Well Field Tracer Test Methods
- Spent Fuel Dissolution Model
- Performance Assessment Technology
- Construction-Testing Integration
- Radiogenic Isotopic Methods
- Flow & Transport
- Geochemical Modeling
- Disturbed Zone Effects
- Fluid Transport Characterization
- Multi-Phase Flow in Fractured Rocks
- Seismic Imaging
- Mechanisms Controlling Sorption
- Borehole Fluid Logging
- OECD/NEA Thermochemical Data Base
- Geochemical & Transport Code Field Validation, New Zealand
- Poços de Caldas Natural Analogue Project, Brazil (1985-1991)
- Alligator Rivers Analogue Project, Australia (completed 1992)
- OECD/NEA Stripa Project Phase 3 (completed 1991)
- CEC CHEMVAL
- INTRAVAL



USDOE/YMP
INTERNATIONAL
PROGRAMS
YMP
IPCG
BILATERAL
Agreements
MULTINATIONAL
Cooperation
OECD
IAEA
CEC
OECD/NEA
OCDE/AEN
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International Atomic Energy Agency
(IAEA)
Vienna, Austria


Gobi Desert - Northwest China
CHINA
IAEA Advisory
Group on Siting & Site
Characterization 2002
Great Wall
Dunhuang, Gansu Province

## Selected Multinational Technical Projects

- **DECOVALEX**
  **Multinational group on coupled thermal, hydrologic, mechanical, and chemical processes in radionuclide release and transport**
- **PSACOIN, INTRACOIN, HYDROCOIN, and INTRAVAL**
  **Multinational projects for conduct of baseline comparative exercises for verification and validation of geosphere and performance assessment models**
- **MULTINATIONAL NATURAL ANALOGUE PROJECTS**
  - **Poços de Caldas (Minas Gerais, Brazil)**
  - **Alligator Rivers (Northern Territory, Australia)**
  - **Oklo (Gabon, Africa)**
  - **Cigar Lake (Saskatchewan, Canada) [under DOE-AECL SA-2]**



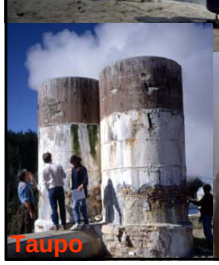
## NATURAL ANALOGUE STUDIES

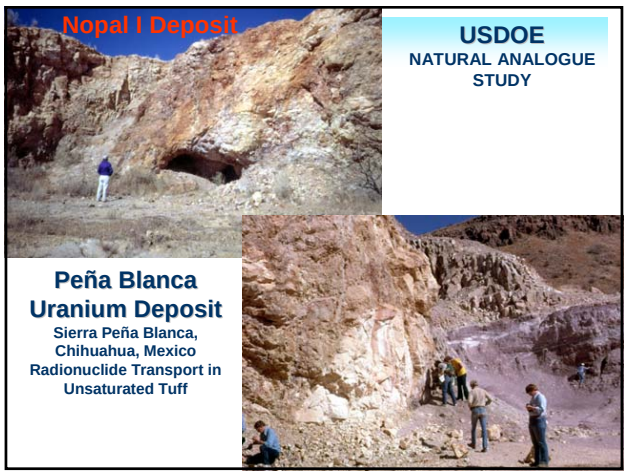
- **Natural Analogue Advisory Group, USDOE**
- **Natural Analogue Working Group / CEC**
- **Poços de Caldas Project, Brazil**
- **Alligator Rivers Analogue Project, Australia**
- **New Zealand Geochemical and Transport Code Field Validation Project**
- **Cigar Lake Natural Analogue, Saskatchewan**
- **Oklo As An Analogue Project / CEC-CEA**
- **Peña Blanca Uranium Deposit, Mexico (US)**
- **Anthropogenic Analogues - Unsaturated Zone (US)**




## NEW ZEALAND

**North Island**
**Taupo Volcanic Zone**
**Geochemical**
**Transport Code**
**Geothermal Field**
**Validation Project**





Nopal I Deposit
USDOE
NATURAL ANALOGUE STUDY
Peña Blanca Uranium Deposit
Sierra Peña Blanca, Chihuahua, Mexico
Radionuclide Transport in Unsaturated Tuff


OCRWM INTERNATIONAL PROGRAM
USDOE
Bilateral Agreements:
Active or being finalized
BILATERAL AGREEMENTS
NWMO
POSIVA
ANDRA
CEA
JNC
NUMO
Minatom RAS
ENRESA
SKB
NAGRA
NIREX
CEC
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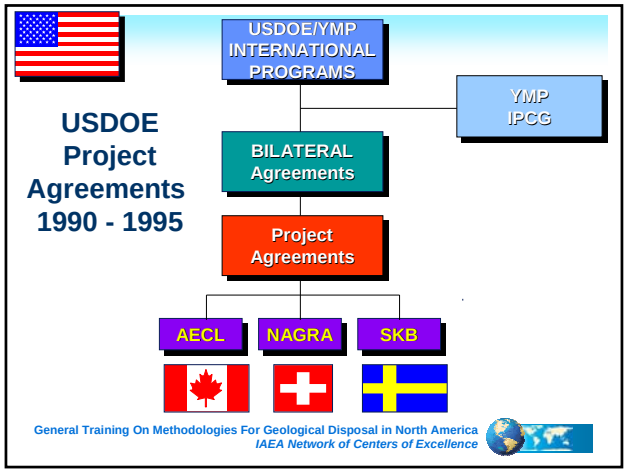
USDOE/YMP INTERNATIONAL PROGRAMS
YMP IPCG
USDOE Project Agreements 1990 - 1995
BILATERAL Agreements
Project Agreements
AECL
NAGRA
SKB
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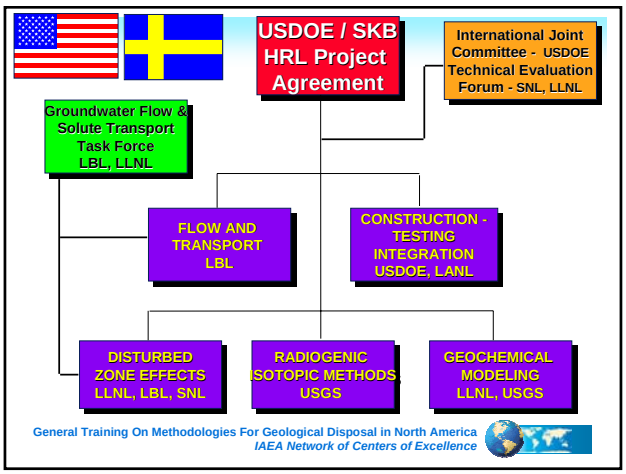
USDOE / SKB
HRL Project
Agreement
International Joint
Committee - USDOE
Technical Evaluation
Forum - SNL, LLNL
Groundwater Flow &
Solute Transport
Task Force
LBL, LLNL
FLOW AND
TRANSPORT
LBL
CONSTRUCTION -
TESTING
INTEGRATION
USDOE, LANL
DISTURBED
ZONE EFFECTS
LLNL, LBL, SNL
RADIOGENIC
ISOTOPIC METHODS
USGS
GEOCHEMICAL
MODELING
LLNL, USGS
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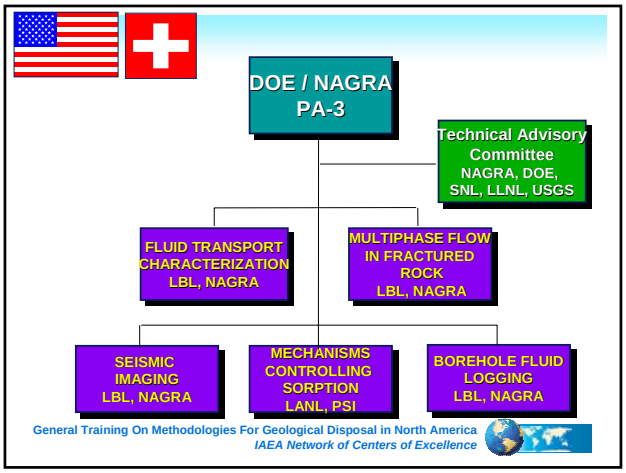
DOE / NAGRA
PA-3
Technical Advisory
Committee
NAGRA, DOE,
SNL, LLNL, USGS
FLUID TRANSPORT
CHARACTERIZATION
LBL, NAGRA
MULTIPHASE FLOW
IN FRACTURED
ROCK
LBL, NAGRA
SEISMIC
IMAGING
LBL, NAGRA
MECHANISMS
CONTROLLING
SORPTION
LANL, PSI
BOREHOLE FLUID
LOGGING
LBL, NAGRA
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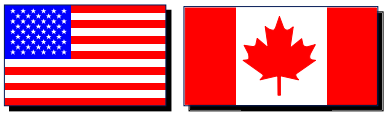
SWITZERLAND
Grimsel Test Site
Underground Rock Laboratory
Grimsel Pass

## An Example of Bilateral Technical Cooperation

- USDOE – AECL
- BILATERAL COOPERATIVE AGREEMENT SA-2



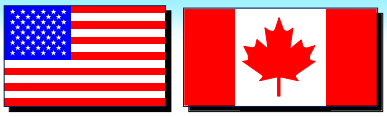


## USDOE / AECL BILATERAL UMBRELLA AGREEMENT

- 1982: Signed agreement for information exchange in radioactive waste management
- 1987: Extended for 5 year period
- 1992: Extended for 1 year period
- 1993: Extended for 1 year period
- 1994: Extended for 1 year period

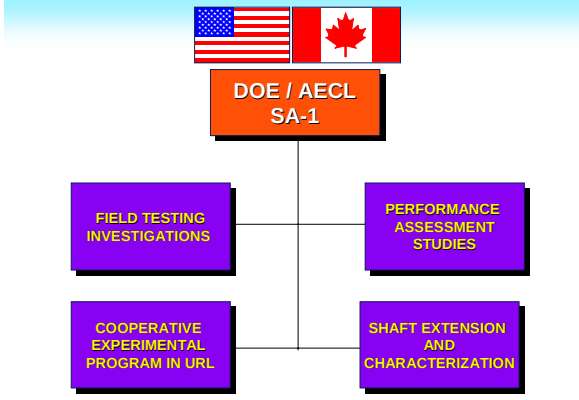
- Due to changes in the current role of AECL in Canada's nuclear waste management program, the Agreement has lapsed.





**DOE / AECL Bilateral Umbrella Agreement**

**DOE / AECL Subsidiary Agreement No. 1**






## SUBSIDIARY AGREEMENTS No. 1 (SA-1) to No. 2 (SA-2)

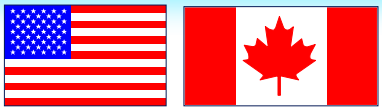
- 1986: Subsidiary Agreement No. 1 Signed
- 1987: U.S. Congress passed the Nuclear Waste Policy Amendments Act (NWPAA)
- NWPAA phased-out all research designed to evaluate suitability of crystalline rocks as a potential repository host medium
- 1988: Previous agreement (SA-1) "Set Aside" at the request of DOE
- AECL and DOE agreed to negotiate a revised cooperative program: Subsidiary Agreement No. 2 (SA-2)



## USDOE / AECL
## SUBSIDIARY AGREEMENT 2 (SA2)

United States Department of Energy (USDOE)
Office of Civilian Radioactive Waste Management (OCRWM)
Yucca Mountain Project (YMP)

Atomic Energy of Canada Limited (AECL)



**DOE / AECL Bilateral Umbrella Agreement**

**DOE / AECL Subsidiary Agreement No. 2**



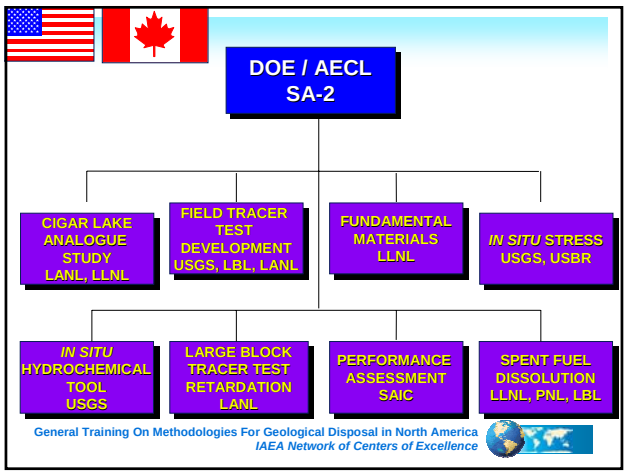
## SUBSIDIARY AGREEMENT No. 2

- Period for negotiations: 1988 - 1991
- Agreement signed: September 1991
- 5 Year Technical Agreement
- Cooperative conduct of R&D
- More than 20 tasks were initially proposed and 8 tasks were selected for cooperation
- By design, none of the selected tasks were conceived to be specific to particular sites and/or specific geologic media



## Tasks Proposed for SA-2

- Buffer Container Experiment
- Cigar Lake Natural Analogue Study
- Carbon 14 Dating of Groundwater
- Fundamental Materials Investigations (Concretes)
- Heated Block Test
- Hydrochemical Tool: Laboratory & Field Testing
- *In-Situ* Stress Determination
- International Topical Workshops
- Large Block Tracer Test - Near Field Geochemistry
- Large Block Tracer Test - Retardation Models
- Mine-By Experiment
- Multi-Level Sampler
- Multiple Well Field Tracer Test Methods
- Near-Field Geohydrology Instrumentation
- Performance Assessment Technology Exchange
- Project Controls Development
- Shaft Sealing / Backfilling
- Spent Fuel Dissolution Model
- URL Facility Operations & Controls
- Waste Container Fabrication / Inspection




## SUBSIDIARY AGREEMENT No. 2

- Much of the experimentation performed employed AECL facilities and equipment unavailable in U.S.
- DOE participated in planning tests and analyzing experimental results
- AECL facilities included two facilities in Manitoba: the Whiteshell Nuclear Research Establishment and the Underground Research Laboratory (URL)



## COST BENEFIT ANALYSIS

- Computation for SA2
  (Value: US$1,000s)
  - Expected value of investigations: 43,385
  - Additional capital costs: 13,500
  - Facility operational costs: 23,500
  - Est. value of AECL expertise: 25,195
    - Total estimated benefit: 105,580
    - Total cost US participation: 20,133
    - Benefit / Cost ratio: 5.2

Notes:
1) Additional capital costs: Costs of constructing in the U.S., AECL facilities not otherwise available to DOE.
2) Facility operational costs: Costs of operating surface and subsurface facilities required for these investigations.
3) Value of AECL expertise: Combined value of AECL technical expertise, procedures, and data available to conduct the cooperative program.

## FUNDAMENTAL MATERIALS

- Objective:
  - Developed a foundation for predicting the long-term mechanical and chemical behavior of cements as sealing materials at elevated temperatures for extended periods of time.
- Task Description:
  - Determined effects of elevated temperatures on mechanical and chemical properties of sealing materials.
  - Conducted high temperature tests at AECL facilities (up to 100$^{o}$C) to permit calculation of properties up to 200$^{o}$C - 240$^{o}$C.
  - Extended thermodynamic models of cement-based sealing materials.
  - Developed models for interactions between sealing materials and rocks.



## *IN SITU* STRESS DETERMINATION

- Objective:
  - Developed improved analytical methods /instruments for stress determination in fractured rock, using existing AECL-developed instrumentation as a basis.
- Task Description:
  - Developed improved stress measuring techniques for fractured rock.
  - Evaluated stress measuring techniques at AECL's URL.
  - Modified existing instruments and techniques developed and used by AECL.
  - Modified interpretation of 3-D stress field techniques developed and used by AECL.
  - Developed improved understanding of effects of scale, structure and anisotropy on rock properties.



## SPENT FUEL DISSOLUTION

- Objective:
  - Constructed a model for the long-term dissolution of spent fuel by investigating parameters affecting the rate of oxidative dissolution of uranium dioxide under both alpha and gamma radiation fields.
- Task Description:
  - Developed Mechanistic Model for rate of oxidative dissolution of $UO_2$.
  - Assessed long-term dissolution behavior of spent fuel.
  - Designed, conducted, and modeled electrochemical behavior of spent fuel.
  - Studied effects of radiation on dissolution chemistry.



## LARGE BLOCK TRACER TEST

- Objectives:
  - Investigated radionuclide transport along fractures at AECL's Large Block Radionuclide Migration Facility to refine techniques to measure tracers in large scale fractures.
  - Calibrated and evaluated appropriate numerical models.
- Task Description:
  - Tested radionuclide migration using tracers.
  - Tested artificial and natural fractures in blocks of Yucca Mountain Topopah Springs Tuff.
  - Developed models for radionuclide migration at large scale.
  - Developed techniques to measure tracer sorption.
  - Calibrated and tested mathematical models for radionuclide migration.



## *IN SITU* HYDROCHEMICAL TOOL

- Objectives:
  - Conducted comprehensive laboratory and field tests of a hydrochemical borehole tool developed in Sweden for potential use at Yucca Mountain.
  - Calibrated tool for various ranges of pressure, temperature and solution chemistry.
- Task Description:
  - Tested performance of Swedish borehole tool.
  - Conducted laboratory tests at the "unique" AECL *Artificial Borehole System* and field site at Whiteshell Laboratories.
  - Calibrated tool for downhole Eh, pH, pressure and temperature at various groundwater chemistries.
  - Developed data collection techniques & sampling system.
  - Developed and tested hardware and software for use at Yucca Mountain.



## CIGAR LAKE ANALOGUE STUDY

- Objective:
  - Used actinide and fission-product geochemistry to understand processes influencing the production, retention, and dispersion of radionuclides in the natural environment to evaluate uncertainties for PA.
- Task Description:
  - Studied unique high-grade uranium deposit.
  - Observed, analyzed, and understood processes involving radionuclide migration and retention.
  - Measured migration of Pu, Tc, and radioactive Iodine.
  - Built confidence in radionuclide transport models.
  - Determined abundance and behavior of natural radionuclides in a highly reduced uranium ore body as it was oxidized.



## Cigar Lake Workshop

**Winnipeg, Manitoba, Canada**



## FIELD TRACER TEST DEVELOPMENT

**Objectives:**

- **Prototype test and modify instruments, equipment, and techniques used to test saturated zone borehole complex at Yucca Mountain.**
- **Conduct integrated testing program at dedicated site exhibiting uncomplicated fracturing.**
- **Determine scale effects in fluid transport tests and develop multidisciplinary approach to describe and predict fluid flow in fractured rock.**
- **Compare discontinuous fracture network model with equivalent porous media modeling approach.**
- **Develop improved fluid flow tests and data analyses for fractured rock.**
- **Develop and test multidisciplinary approach to describe fluid flow: multiple-well hydraulic tests, tracer tests, and seismic imaging.**



## PERFORMANCE ASSESSMENT

- **Task Description:**
  - **Verified AECL's SYVAC3 TSPA software code.**
  - **DOE accessed AECL's highly developed, well-documented SYVAC3 Total Systems code.**
  - **DOE staff gained experience in developing, testing, and quality-assuring a performance assessment software package.**
  - **DOE staff verified subsystems codes including waste package release, radionuclide transport, and radiation dose.**
- **Tools & Skills Developed:**
  - **DOE staff learned much concerning code verification process and developed automated tools that aided in testing code modules.**

## INTERNATIONAL COOPERATION

Summary of Benefits

- International Technical Cooperation is an excellent and proven method for a Developing Program to use to:
- Build a strong scientific and technical program
- Train technical program staff for site characterization, performance assessment and repository engineering
- Leverage efforts and costs through bilateral and international cooperative R&D programs