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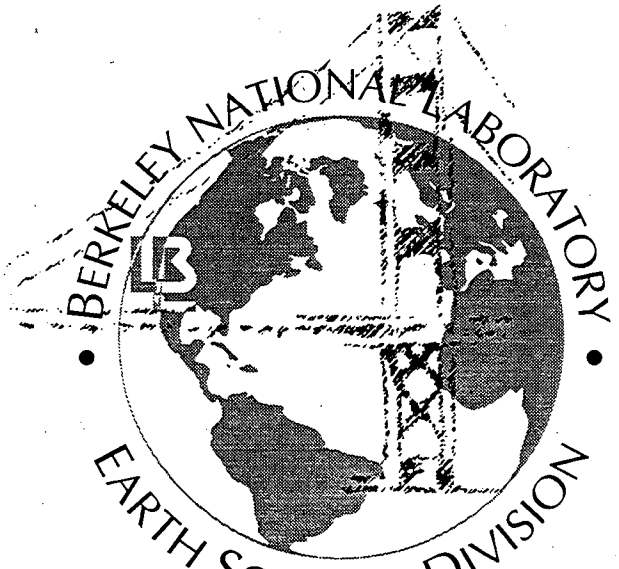

FRANCE BERKELEY

Workshop on Nuclear Waste Disposal

December 12 - 14, 1994

Convenors:

Prof. Marcel Arnould
École des Mines
Paris, France

Dr. Gudmundur Bodvarsson
Ernest Orlando Lawrence Berkeley National Laboratory
Berkeley, California

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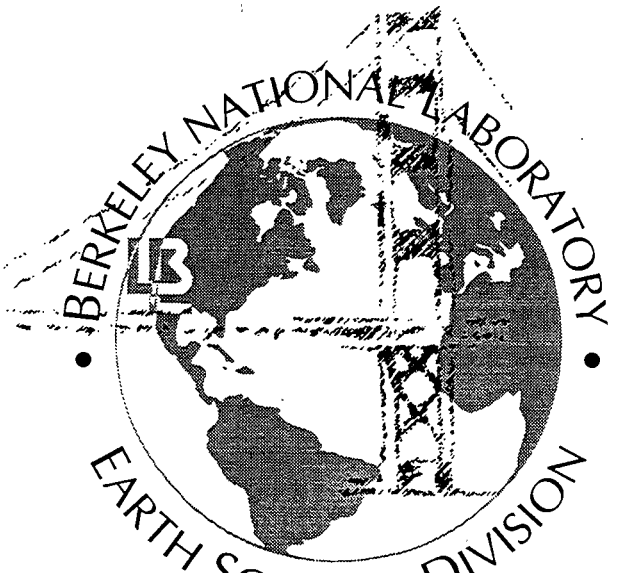

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SUMMARY

The France Berkeley Workshop on Nuclear Waste Disposal was held in Berkeley December 12-14, 1994. The idea of the workshop was conceived in a conversation between Dr. Jacques Lévy, Président de la Conférence des Grandes Écoles and Dr. Charles Shank, Director of Lawrence Berkeley National Laboratory. They wanted to establish a collaborative research program between France and Berkeley in the spirit of the already established Berkeley-France fund that supports visits of scientists between U.C. Berkeley and French universities. The subject matter of the workshop, nuclear waste, was considered appropriate as this is a major problem facing both the U.S. and France. The agenda of the workshop is given in Attachment A.

The France Berkeley Workshop convened on the Berkeley Campus with the participation of Dr. J. Lévy and twenty French scientists from various French technical and scientific institutions including École des Mines (Paris and Fontainebleau), Université de Poitiers, Institut National Polytechnique de Lorraine, École Polytechnique, Commissariat l'Énergie Atomique (CEA), and Électricite De France (CDF). The International Atomic Energy Agency in Vienna (Agence Internationale de l'Énergiei Atomique) also sent a representative to the workshop. The U.S. participants were primarily scientists from Lawrence Berkeley National Laboratory (LBNL) and U.C. Berkeley, with additional participants from U.S. Geological Survey (USGS), Lawrence Livermore National Laboratory (LLNL), and Scientific Applications International Corp. (SAIC). The U.S. Department of Energy (DOE) that oversees the development of geological repository for nuclear waste in the U.S., and their counter-part in France, Agence nationale pour la gestion des déchets radioactifs (ANDRA) sent scientific and managerial staff to the workshop. A bilateral agreement is currently being negotiated between DOE and ANDRA on nuclear waste disposal. The meeting was also attended by the Scientific Advisor of the French Embassy, Washington DC and the Scientific Attaché, French General Consulate, San Francisco. Attachment B gives names, affiliations and addresses of the participants in the workshop.

The workshop began with keynote addresses by Dr. P. Oddone, Deputy Director of LBNL, Dr. J. Lévy, Président de la Conférence des Grandes Écoles, S. Plattard, Scientific Counselor of the French Embassy, Mrs. R. André-Jehan, Special Advisor to the Director General of ANDRA, A. Régent, Programme Entreposage-Stockage-Cycle du Combustible (CEA), J.M. Gras, Département Etudes et Recherches (EDF), J.R. Dyer, Deputy Project Manager of the Yucca Mountain Project (DOE), and J. Tamborini, Secretaire Scientifique du Waste Assessment Technological Review Panel (Agence Internationale de l'Énergiei Atomique). After the keynote addresses, all the participants gave brief

scientific presentations in order to establish common ground and to share knowledge and experience. The participants of the France-Berkeley Workshop represented various disciplines of importance for geologic disposal on nuclear waste including geology, engineering geology, geochemistry, rock mechanics, hydrology, nuclear engineering, and others. Following the presentations, the workshop participants were divided into working groups, each of which addressed specific aspects involved in geologic disposal of nuclear waste. Members of the individual workings groups and their general discussion topics are listed in
Attachment C.

The working groups discussed problems of relevance to the French and U.S. nuclear waste disposal programs and identified common projects and tasks that could be addressed jointly by French and U.S. scientists. These projects ranged in content and complexity from simple technical exchange and more formalized workshops to actual joint research projects on various common problems. The members of the working groups spent many hours during the 2 days of the working group meetings as evidenced by the quantity and quality of the research projects that were identified. Attachment D shows all of the projects identified by the working groups. We certainly do not envision carrying out all of research projects, but their identification is an important technical result of the workshop. We have grouped all of these individual projects into four major areas of collaborative research as follows:

I. Flow and Transport Processes
II. Coupled Process Studies
III. Characterization of Fractured/Faulted Rocks
IV. Natural Analog Studies

All of the sub-elements of these four major areas are given in Attachment E. We hope that some of the more important projects can be identified and jointly funded and supported by the appropriate U.S. and French agencies.

In closing, we would like to thank all the participants of the Workshop for their tremendous efforts in ensuring the success of the workshop through hard work, debates, and fruitful results. If nothing else, this workshop served a very useful purpose of bringing together scientists of the highest caliber from the U.S. and France to discuss common problems and to develop personal relationships that are essential for collaborative ventures of the sort proposed in this workshop. We are confident, however, that the results of this workshop will lead to fruitful future collaborations between France and the U.S. on geological disposal on nuclear waste and allow us to jointly find essential solutions to this very important problem.

Prof. Marcel Arnould *
École des Mines

Dr. Gudmundur S. Bodvarsson
Lawrence Berkeley National Laboratory

* The French delegates would like to thank the Nuclear Waste Department and Earth Sciences Division of Lawrence Berkeley National Laboratory for their very friendly and efficient organization of the meeting.

Agenda

MONDAY, DECEMBER 12, 1994

8:00-8:15	Registration (Clark Kerr Campus, Building 14)
8:15-8:30	Welcome/Introductions
	G.S. Bodvarsson, Head, Nuclear Waste Dept., LBNL
	M. Arnould, Professeur, École des Mines
8:30-9:00	Opening Remarks
	P. Oddone, Deputy Director, LBNL
	J. Lévy, Chairman Conference des Grandes Écoles
	S. Plattard, Scientific Counselor, French Embassy, Washington D.C.
9:00-10:20	French Nuclear Waste Disposal Program
	Mrs. Raymonde André-Jehan, Special Advisor to the Director General, ANDRA
	Alain Regént, Programme Entreposage-Stockage-Cycle du Combustible, CEA
	Jean-Marie Gras, Département Études et Recherches, EDF
10:20-10:30	Coffee Break
10:30-11:30	U.S. Nuclear Waste Disposal Program
	Russ Dyer, Deputy Project Manager, Yucca Mountain Project, DOE
11:30-12:00	International Atomic Energy Commission
	J. Tamborini, Scientific Secretary of WATRP
12:00-1:00	Lunch, Clark Kerr Campus
1:00-3:30	Scientific Presentations by Participants
3:30-3:45	Coffee Break
3:45-6:15	Scientific Presentations by Participants
8:00	Banquet: Enoteca Mastro Restaurant, 933 San Pablo Ave., Albany

Agenda

TUESDAY, DECEMBER 13, 1994

8:00-10:00	Scientific Presentations by Participants
10:00-10:15	Coffee Break
10:15-10:30	Organization of Working Groups on Joint Research Projects
10:30-12:00	Working Groups Meet
12:00-1:00	Lunch, Clark Kerr Campus
1:00-6:00	Working Groups Meet
	Dinner: Everyone on their own

WEDNESDAY, DECEMBER 14, 1994

8:00-9:30	Working Groups Finalize Contributions
9:30-10:30	Presentations by Working Group Leaders
10:30-10:45	Coffee Break
10:45-11:45	General Discussion/Outline of White Paper on Workshop
11:45-12:00	Summary of Workshop M. Arnould/G.S. Bodvarsson
12:00-1:30	Lunch, LBNL
1:30 - 5:00	UC Berkeley/LBNL Tour
5:00 - 7:00	Wine & Cheese Reception: LBNL Building 50A, Room 5132

Participants & Addresses

ORGANIZERS

France:

Marcel Arnould, Conseiller scientifique du CGI, École des Mines-École des Ponts et Chaussées (co-convenor)
Jacques Lévy, Directeur de l'École des Mines de Paris, Président de la Conférence des Grandes Écoles

Berkeley:

Gudmundur Bodvarsson, LBNL (Head, Nuclear Waste Department, co-convenor)
Sally Benson, LBNL (Director, Earth Science Division)
Charles Shank, LBNL (Laboratory Director)

SCIENTISTS

France:

Joël Billiotte, CGI, École des Mines-École des Ponts et Chaussées, Paris (Modeling of Fluids and Colloids in Fractured Rocks)
Bernard Beaudoin, Professeur, CGES, École des Mines, Fontainebleau (Geological Evolution)
Michel Colchen, Professeur, Université de Poitiers (Structural Geology Tectonics)
Jean-Michel Le Cléac'h, CGI, École des Mines-École des Ponts et Chaussées, Paris (Low Level Radioactive Waste)
Emmauel Ledoux, Directeur, Centre d'Informatique Géologique, École des Mines, Fontainebleau (Hydrogeology-Transport Modeling)
Bernard Poty, Directeur du CREGU, Nancy (Recirculation, Granite, Thermal Stability)
Gilles Rousset, Directeur, Groupement pour l'étude des structures souterraines de stockage, École Polytechnique (Blankets Over Waste, Clay Properties)
Jean-Paul Tisot, Professeur, ENSG Institut National Polytechnique de Lorraine (Soil Mechanics, Oceanic Sediments)
Yves Leroy, représentant Pierre Berest, Directeur du LMS, École Polytechnique

Berkeley:

John Apps, LBNL (Geochemistry)
Ken Fowler, UCB (Nuclear Engineering)
Kenzi Karasaki, LBNL (Hydrology, Fluid Flow in Fractured Rocks)
Jane Long, LBNL (Hydrology, Fracture Rocks-Granite)
Ernie Majer, LBNL (Geophysics/Geology)

SCIENTISTS (CONT.)

Berkeley (cont.):

Larry Myer, LBNL (Rock Mechanics, Clay Stability)
Per Peterson, UCB (Nuclear Energy)
Karsten Pruess, LBNL (Numerical Modeling of Flow and Transport)
Chin Fu Tsang, LBNL (Fluid Flow and Transport)
Yvonne Tsang, LBNL (Hydrogeology)
Jiamin Wan, LBNL
Joe Wang, LBNL (Hydrogeology)
Paul Witherspoon, UCB/LBNL (Hydrogeology)

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Michel Raynal (Director des Affaires Internationales)

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Alain Regént, Programme Entreposage-Stockage-Cycle du Combustible (Director of Interim Storage)

Electricite' De France (EDF)
Jean-Marie Gras Département Études et Recherches (Assoc. Director of Study and Research)

Agence Internationale de l'Énergie Atomique, Vienne
Jacques Tamborini, Secrétaire Scientifique du Waste Assessment Technological Review Panel (WATRP)

French Embassy
Serge Plattard (Scientific Counselor)
Pascal Revel (Scientific Attache)

DOE
Russ Dyer (Deputy Project Manager)
Bob Levich (Manager, International Programs)
Ardyth Simmons (Team Leader, Geochemistry)
Russ Patterson (Team Leader, Hydrology)

USGS
Zell Peterman (Isotope Chemistry)

LLNL
Ann-Marie Meike (Man-Made Materials)

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Heidi Lohn (Hydrology)

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Rock/water chemistry and colloidal effects in tuffs, granites, clays and salts

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GROUP 5

Technology development in the storage of low to medium level waste

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Working Group Members

(Overseers: Prof. M. Arnould and Dr. G.S. Bodvarsson)

Group 1.	Geological and geophysical characterization methods for fractured rock masses
	Raymonde André-Jehan, ANDRA **Bernard Beaudoin**, France **Sally Benson**, LBNL **Michel Colchen**, France **Jean Michael le Cleac'h**, France **Bob Levich**, DOE **Jane Long,** LBNL **John Stuckless**, USGS **Jacques Tamborini**, IAEA, Vienna
Group 2.	Hydrological and geomechanical testing and monitoring of fractured/faulted rocks
	Kenzi Karasaki, LBNL **Yves Leroy,** France **Larry Myer**, LBNL **Russ Patterson**, DOE **Jean Paul Tisot**, France **Joe Wang,** LBNL **Paul Witherspoon**, UCB
Group 3.	Data integration, property scale-up, flow and transport modeling and validation
	Joel Billiotte, France **Emmanuel Ledoux**, France **Heidi Lohn**, M&O **Karsten Pruess**, LBNL **Alain Regent**, CEA **Yvonne Tsang**, LBNL **Chin Fu Tsang**, LBNL
Group 4.	Rock/water chemistry and colloidal effects in tuffs, granites, clays and salts
	John Apps, LBNL **Don DePaolo**, UCB **Jean-Marie Gras**, EDF **Zell Peterman,** USGS **Bernard Poty**, France **Michel Raynal,** ANDRA **Ardyth Simmons,** DOE **Jiamin Wan,** LBNL
Group 5.	Technology development in the storage of low to medium level waste
	Michel Deveughele, CGI **Ken Fowler**, UCB **Ann-Marie Meike,** LLNL **Per Petterson**, UCB **Gilles Rousset**, France

Research Topics

Group 1. Geological and geophysical characterization methods for fractured rock masses

- Advanced geological and geophysical characterizing techniques
- Continuity of stratigraphic layers and definition of homogeneous zones
- Formation and connectivity of fracture networks
- Effects of faults and major pathways
- Relation between petrography (fabric, mineralogy), hydrological and mechanical behavior
- Research of "favorable" facies (e.g. "altered facies" of granitoids) for underground storage of wastes

Group 2. Hydrological and geomechanical testing and monitoring of fractured/faulted rocks

- Characterization and properties of unsaturated media
- Deformation of clays (hysteresis, transient effects)
- Fracture/matrix flow and transport interactions
- Effects of faults and major pathways
- Baseline measurements and monitoring activities
- Hydrologic field tests in very low permeability rocks
- Large scale field tests (e.g. ventilation tests)
- Multi-phase fluid effects on flow and transport
- Effects of temperature on the near-field environment

Group 3. Data integration, property scale-up, flow and transport modeling, and validation

- Data analysis and conceptual models
- Numerical codes and modeling approaches
- Muliphase effects on flow and transport
- Discrete and fracture network models
- Model validation
- Parameter correlations
- Parameter uncertainties
- Scaling-up of properties (geostatistics) in fractured rocks masses
- Large scale field tests (e.g. ventilation tests)
- Natural analogs (OKLO, Gabon, Cigar Lake, etc.)
- Effects of faults and major pathways

Group 4. Rock/water chemistry and colloidal effects in tuffs, granites, clays and salts

- Water ages/isotopes, actinide chemistry
- Effects of temperature on the near-field environment
- Multi-phase fluid effects on chemical reactions and parameters
- Colloidal transport
- Formation and migration of gases (CH_4, CO_2, H_2, and HCL)

Group 5. Technology development in the storage of low to medium level waste

- Multi-layered covers
- Concrete contamination

Potential Research Projects Identified by Working Groups

GROUP 1
GEOLOGICAL AND GEOPHYSICAL CHARACTERIZATION METHODS FOR FRACTURED ROCK MASSES

Group Leader: Jane Long (LBNL)
Members: Per Peterson(UCB), Jean-Michel Le Cléac'h (École des Mines), Raymonde André-Jehan (Andra), Bob Levich (DOE), Sally Benson (LBNL), John Stuckless (DOE), Jacques Tamobornini (IAEA, Vienna) , Bernard Beaudoin (École des Mines), and Michael Colchen (Poitiers Univ)

VOLCANISM

1. Title: **Evolution of Volcanism in Space, Time and Volume/ Risk Assessment of Volcanism**

Description of Project: Develop a unifying theory or model to 1) explain volcanic data and use this model to project events into the future, 2) predict their location and , 3) assess the consequences. There should first be an information exchange to determine if and where there is a possibility for collaboration. YMP has to do a probabilistic approach, ANDRA does not.
French Contact: Bernard Beaudoin (École des Mines)
US Contact: Bruce Crowe (LANL), Don DePaolo (UCB/LBNL)
Duration: An initial meeting of experts would evaluate more specific topics and communality. A several day or week long meeting or two meetings is possible, including several days of field visits to Yucca Mtn. Area and site in France.
Funding : $25 - 50K for scoping workshop including travel costs.

NATURAL ANALOGUES

2. *Title*: Use of Natural Analogue Sites to Evaluate the Geologic Features and Processes That Dominate Transport and Validation of Methods for Locating and Characterizing These Features

Description: Most analogue studies have been focused on geochemistry. We could revisit previous analogue study sites to see if the geologic features which dominate flow and transport can be identified and then can they be seen with geophysical methods.
French Contact: Patrick Lebon, Michael Colchen, Razack (Poitiers Univ)
US Contact: Jane Long, Ernie Majer (LBNL) / Dwight Hoxie (USGS)
Duration: 3 - 5 years depending on identifying the right site
Funding: depends completely on the site, e.g., whether holes need to be drilled etc.

3. *Title*: Taupo Volcanic Zone Studies

Description: Geochemical field validation of geochemical models (EQ3/EQ6). The data is available. We propose an information exchange.
French Contact: Patrick Lebon (Andra)
US Contact: Anne Marie Meike (LLNL)
Duration: 1 month
Funding: $25K

4. *Title*: Workshop to identify New analogue sites that have not yet been investigated

Description: A workshop would be held to determine if there are other types of sites that should be examined. For example: Radionuclide migration from US nuclear tests (NTS) or natural migration of radionuclides in crystalline rocks.
French Contact: Jacques Tamborini (IAEA, Vienna) / Emanuel Ledoux (École des Mines)
US Contact: John Stuckless (DOE)/ Don DePaolo(UCB/LBNL)
Duration: 12 months
Funding: $50K

GEOLOGIC HETEROGENEITY INCLUDING FRACTURES

5. *Title*: Identification of Critical Geologic Features That affect hydraulic and repository performance

Description: Joint evaluation of data from sites in France and in the US to develop conceptual models and tests to evaluate these models. For example, features which may be important are cementation, fracture connectivity, alteration, extensional features, fracture intersections, stratigraphy/lithology. We could form a study group which would meet once or twice a year to review Yucca Mountain data and site data from France or a particular type of heterogeneity. This group should include geologists, hydrologists, geochemists, geophysicists.
French Contact: Bernard Mouroux (Andra) / Jean-Michel Le Cléac'h (École des Mines)
US Contact: Bo Bodvarsson, Jane Long (LBNL) / Ed Kwicklis (USGS)
Duration: 3 years
Funding: $50K /year

6. *Title:* Combined hydro-mechanical, seismic and two-phase flow studies in single fractures

Description: Collaboration on studies on-going at the HRL facility in Sweden where BRGM/ANDRA are performing hydro-mechanical studies and the US could add seismic, geochemical, and two-phase flow behavior.
French Contact: Patrick Lebon
US Contact: Jane Long, Larry Myer (LBNL) / Zell Peterman (USGS)
Duration: 1 to 3 years
Funding: $100K/ year add on

7. *Title:* Fracture system geometry in three-dimensions and its control on hydrology

Description: Find examples of fracture systems in the field that are exposed in 3D, build models of three-dimensional fracture system genesis to predict 3D morphology and geometry, model these, do parameter studies, apply methods at a system where hydrologic data is also available. Includes both brittle and ductile systems. Investigate whether these can be identified using geophysical techniques.
French Contact: Michel Colchen, Razack (Poitiers Univ.) / Cojean (École des Mines)
US Contact: Rick Spengler (USGS) / Jane Long (LBNL)
Duration: 3 years
Funding: $300K/yr

TECTONICS

8. *Title:* Comparison of the US/French approaches to seismic hazard analysis

Description: French would be invited to participate in US seismic hazard analysis workshops.
French Contact: Pierre Godefroy (BRGM, Marseilles)
US Contact: John Whitney (USGS)
Duration: 2 years
Funding: $50K/year

9. *Title*: Effects of tectonic activity on hydrology and over-pressure

Description: Compare experimental data and records of past behavior. Explore alternative uses of data. Develop mathematical models of hydrologic response to tectonic activity.
French contact: Bernard Beaudoin (École des Mines)
US contact: Chris Fridrich (USGS) / Bo Bodvarsson (LBNL)
Duration: 3 years
Funding: $50 - $100K /year

10. *Title*: Fault Proximity

Description: Determine how close a repository may be to an active fault given the size of the probable earthquakes. Determine the effects of earthquakes on repository integrity.
French Contact: Pierre Godefroy
US Contact: Frank Tsai (M&O) / Francois Heuze (LLNL) / Larry Myer (LBNL)
Duration: 1 years
Funding: $100K

GEOLOGIC CHANGES OVER TIME

11. *Title*: Geoprospective

Description: In France, École des Mines, BRGM, and ANDRA participate in the Geoprospective Program. US scientists may wish to participate. The purpose of this program is to reflect on the past and to project the effects and consequences into the future. These trends include the velocity of geological phenomena and time scales involved and the varying levels of complexity in interactions of these phenomena.
French Contact: Bernard Beaudoin (École des Mines)
US Contact: Don DePaolo (UCB/LBNL) / Rick Forrester (USGS)
Duration: On going
Funding: $25 -100K/year/participant

GEOPHYSICS

12. *Title*: Midscale imaging of fractures and heterogeneities

Description: Collaborate on the development of techniques for imaging in the midscale near a repository.
French Contact: Mouroux (Andra)
US Contact: Ernie Majer (LBNL)
Duration: 3 years
Funding: $100k/year

GROUP 2
HYDROLOGICAL AND GEOMECHANICAL TESTING AND MONITORING OF FRACTURED/FAULTED ROCKS

Group Leader: Kenzi Karasaki (LBNL)
Members: Russ Patterson (DOE), Yves Leroy (École Polytechnique), Larry Myer (LBNL), Gilles Rousset (École Polytechnique), Jean Paul Tisot (Laboratoire de Geomecanique), Joe Wang (LBNL), and Paul Witherspoon (LBNL)

1. Title: Disturbed Zone Assessment

Description:
- Objective - to measure extent of damage induced byexcavation process/thermal load in low matrix permeability rock
- Use special probes for local permeability measurements near excavation wall
- Use geophysical measurements in conjunction with permeability measurements
- Develop correlations between geophysical and hydrologic measurements
- Development of predictive tool (analytic or numerical) for evolution of damage with time (temperature and stress state)
- Bench marking with laboratory experimental results
- Disturbed zone assessment relevant to both French and US programs

French Contact: Jean-Paul Tisot (Laboratoire de Geomecanique)
US Contact: Larry Myer (LBNL)
Duration: initial testing of 2 years, followed by longer term testing for thermal effect
Funding: _____

2. *Title:* Laboratory Testing of Low Permeability Rocks Under Stress and Temperature

Description:
- Thermo-mechanical behavior as function of stress, temperature and water content on materials relevant to both programs; technique development and validation of methodology
- Permeability measurement as function of stress, and temperature; both for argillaceous rocks and partially saturated rocks; technique development and validation of methodology
- Time effects on mechanical response and permeability; subcritical crack growth; water content and chemistry
- Laboratory measurement on rocks types of interest to both groups and theoretical model development

French Contact: Yves Leroy (École Polytechnique)
US Contact: Larry Myer (LBNL)
Duration: 3-5 year duration
Funding: _____

3. *Title:* Laboratory Study of Hydromechanical Behavior of Fractures

Description:
- Characterization of monthology of fracture surfaces
- Constitutive law for fractures
- Flow and transport in fractures as function of stress state
- Relationship between geophysical and hydrologic properties of fractures
- Laboratory measurements and theoretical model development
- Direct application to both French and US fractured rock programs

French Contact: Roger Cojean (CGI École des Mines) / Jean-Paul Tisot (Laboratoire de Geomecanique)
US Contact: Larry Myer (LBNL)
Duration: 3-5 year duration
Funding: _____

4. Title: **Development of Field Testing Methodology for Fractured Rocks at the Raymond Field Site**

Description: The rock mass at the Raymond Field Site is fractured granite. The site will be used to develop techniques and instrumentation for both Yucca Mountain and French fractured sites. The tests will include hydrologic and tracer tests. Modeling studies will be also carried out to interpret these field tests and to derive effective values for the hydrologic and transport parameters.
French Contact: Roger Cojean (CGI École des Mines) / Jean-Paul Tisot (Laboratoire de Geomecanique)
US Contact: Kenzi Karasaki (LBNL)
YMP relevance: C-holes, SZ tests
French Interest: Fractured granite testing
Duration: 4 yrs
Funding:_____

5. Title: **Underground Laboratory Testing**

Description: There are certain types of tests that can only be done in an underground test facility. In this task we will design and develop methodology and instrumentation for large scale underground testing. Some of the preliminary tests can be performed in P-tunnel/Calico Hills/ESF. The underground tests include:
1. Large Scale Permeability Tests
2. Tracer Tests
3. Mechanical Stability Studies
4. Thermal Effects
5. Scaling Effects
6. Fracture and Fast Path Characterization
7. Water Age Dating
8. Groundwater Travel Time Evaluation
9. Coupled Thermal-Mechanical-Hydrologic Effects
    a) Heated Room Test
    b) Block Tests
    c) Modeling

French Contact: Gilles Rousset (École Polytechnique)
US Contact: Paul Witherspoon, Joe Wang (LBNL)
YMP relevance: P-tunnel, Calico Hills, ESF
French Interest: Future underground lab design
Duration: 10 yrs
Funding:_____

6. Title: **Coupled Thermal-Mechanical Hydrologic Effects**

Description: In this task, we will conduct field and modeling studies of thermally induced coupled processes. Field studies will include:
1. Heated Room Tests
2. Block Tests Modeling studies will be separated into two sub-tasks:
3. Near Field Modeling (Package, EBS) d) Far Field Modeling

French Contact: Gilles Rousset (École Polytechnique)
US Contact: Paul Witherspoon, Joe Wang (LBNL)
YMP Relevance: Large Block Tests, ESF French Interest: Prepare modeling of future underground laboratory
Duration: 3 yrs
Funding:_____

GROUP 3
DATA INTEGRATION, PROPERTY SCALE-UP, LOW AND TRANSPORT MODELING AND VALIDATION

Group Leader: Yvonne Tsang (LBNL)
Members: Joël Billiotte (École des Mines), Emmanuel Ledoux (École des Mines), Karsten Pruess, (LBNL), Alain Regent (CEA), and Chin-Fu Tsang (LBNL)

1. Title: OKLO- A Natural Nuclear Waste Repository

Description:

Background -

A research program on Oklo reactor zones is going on under the coordination of CEA in the framework of an EEC contract since early 1991. It will end in June 1995. Current work includes:

1. The characterization of geochemical processes involving fission products within reactor zones and in the near field.
2. The evidence of long distance migration in the past from the reactor zones.
3. The characterization of hydrological pathways through the low permeability overburden of the reactors.
4. Understanding and modeling of the present time transport of elements generated within the reactor zones, taking account of the different geochemical environment of the zones.

During 1995 at the end of the first phase of project, a continuation will be proposed to focus on particular items. This proposal for French/US cooperative project should be consistent and coordinated with the second phase of the EEC program for understanding long term processes and develop credibility for radioactive waste disposal. A CE project meeting is scheduled for Jan. 9-10, 1995 to prepare for the second phase of Oklo study, US scientists are invited.

Scientific Program -

1. Document release and transport of selected RN in the natural environment of Oklo.
2. Modeling of paths leading to criticality, which may be an issue in storing unprocessed spent fuel. Fully coupled modeling capability for Thermo-Hydrological-Chemical processes with neutron generation and transport needs to be developed.
3. Investigate far field isotopic geochemistry to shed light on RN transport.
4. Detailed medium scale (50m) study to refine current understanding of geochemical transport. Particular emphasis will be placed on identifying processes relevant to waste repositories, such as mobilization and precipitation of fissile species due to variable redox conditions.

French Contact: Emmanuel Ledoux (École des Mines) / Alain Regént (CEA)
US Contact: Chin-Fu Tsang (LBNL)
YMP Interest: Oklo is the only natural analog of nuclear waste disposal with long term data, and can make an important contribution to building acceptance and credibility for geologic disposal. It provides a unique opportunity to address issues of criticality.
French Interest: Natural analog to insure that relevant processes are not missed, develop confidence in feasibility of safe geologic disposal.
Duration: 3-4 years
Funding: US effort at least 2.5-3 FTE, French effort to be determined. EC with CEA as a project leader on the French side; OCRWM and YMP on the US side.

2. ***Title:*** **Fundamental studies of colloidal and multi-phase transport in heterogeneous porous and fractured media**

Description:

Background -

2D micro-models and 3D network simulators have been successfully applied to multiphase flow in heterogeneous media (École des Mines - CGI). The micro-model experiments allow to identify basic mechanisms which are included in simulators. The simulations which incorporate more complex geometry define relationship between flow and porous media characteristics. Known measured results on colloid gas-water interface (LBNL), colloid-surface interactions (École des Mines - CIG), and simulations of colloid transport at the pore scale level in saturated porous media (CGI, CIG) form a good basis for the work to be extended to colloidal multiphase transport.

Multiphase flow and transport in fractures is of obvious importance at Yucca Mountain, and it is also expected to play a role in the near-field for repositories in the saturated zone. Recently developed laboratory techniques make possible detailed visualization and precise measurement and control of two-phase flow processes in rough-walled fractures.

Scientific Description -

1. Laboratory micro model study and numerical simulations to understand the colloidal transport: including diffusion into matrix and gas bubble transport.
2. Study of multiphase behavior of fractures: laboratory study in single fractures, surface geometry characterization, numerical simulation, upscaling to fracture network by numerical simulation.

French Contact: Joël Billiotte (École des Mines)
US Contact: Karsten Pruess, Jiamin Wan (LBNL)
YMP Interest: Sorption of colloids at gas-liquid interface may inhibit or enhance transport. Fast migration along preferential paths in fractures is a chief concern.
French Interest: Two phase behavior together with colloidal transport may be a concern in the near field, where gas generation is expected from corrosion, microbial activity and radiolysis.
Duration: 2 years
Funding: 6 months/year each on the US and French side. ANDRA?? YMP

3. ***Title:*** **Modeling of Flow And Transport in Large, Highly Heterogeneous Systems**

Description:

Background -

Large heterogeneous systems commonly encountered in flow and transport related to waste repository place great demands on (1) the ability to model them and (2) the ability to quantify the uncertainty. This project addresses the need for improvements in our present modeling capability.

Scientific Description -

1. Explore alternative conceptualizations and representations of heterogeneity. Develop simplified description on grid-block scale.
2. Improve numerical methods appropriate to different conceptualizations of heterogeneous systems, including more efficient algorithms, and improved space and time discretization techniques. Code developments should take advantage of evolving massively parallel hardware architectures.
3. Develop methods to deal with uncertainty in conceptual models, especially with regard to safety analysis.
4. Demonstrate modeling capabilities by application to appropriate sets of field data.

French Contact: Emmanuel Ledoux (École des Mines)
US Contact: Karsten Pruess (LBNL)
French & YMP Interest: Such modeling capabilities and experience are needed for (i) design and analysis of field tests in site characterization, (ii) repository design, (iii)performance prediction, and (iv) demonstration of regulatory compliance.
Duration: 2-3 years
Funding: -2 FTE /Yr for US, ? on French side. ANDRA?? YMP

GROUP 4
ROCK/WATER CHEMISTRY AND COLLOIDAL EFFECTS IN TUFFS, GRANITES, CLAYS AND SALTS

Group Leader: Ardyth Simmons (DOE)
Members: John Apps (LBNL), Zell Peterman (USGS), Bernard Poty (CREGU), Michel Raynal (ANDRA), Jiamin Wan (LBNL), and Jean-Marie Gras (EDF)

Important research issues originally listed in proposed workshop:
- Water ages/isotopes - paleohydrology
- Actinide chemistry
- Temperature effects on near-field environment
- Chemical reactions involving fluids reactions
- Colloidal transport
- Formation and migration of gases - CH4, C02, H2,N2,HCl

Research interests of individuals in group:

A. Zell Peterman (USGS) - Paleohydrology and geochronology of young materials; use of radiogenic isotopes as natural tracers (87Sr/86Sr - Ca analog); 234U/238U; how water has moved in the past by studying old spring deposits (source of water and when springs were active using 14C, U-series, thermoluminescence, cosmogenic dating), whether deposit represents actual paleo water table; fracture fillings (clays, calcite, opaline silica) as indicators of fluid flux; carbon isotopes as paleoindicators; interest in other sites where there are independent controls to test as validation of results and methods.

B. John Apps (LBNL)
   1. Field-scale and in situ tracer tests in unsaturated environments for estimating hydrologic and chemical properties, e.g. Rainier Mesa P-tunnel and Calico Hills; use of sorbing and non-sorbing tracers, both aqueous and gas-phase (SF6), for testing of ion exchange, estimation of matrix and fracture porosity, high and low diffusion coefficients.
   2. Modeling and experimentation to test use of radionuclide surrogates for Pu, Am, Np, Tc, and fission product radionuclides. Zell noted that natural Sr with a composition different from what exists in host rocks could be used as a tracer.
   3. Development of efficient techniques and improved capability for modeling radionuclide sorption via mechanistic processes (ion exchange, triple-layer model, etc.) Use of parallel processing to improve quantification of uncertainties and to understand sensitivity of model parameters in performance assessments .

C. Jiamin Wan (LBNL) - Colloid transport. Most conceptual models don't distinguish saturated from unsaturated (two-phase) flow. Gas can be generated in saturated zone. Organic substances in aqueous phase may change physical properties from being hydrophobic to hydrophyllic. Risk assessment is needed; combine this research with migration of gases. Improved conceptual and numerical models for colloid transport in unsaturated zone. In laboratory, use fracture micromodel and column experiments with site-specific chemical conditions.

D. Michel Raynal (ANDRA) - France is not as concerned with an unsaturated medium as is the U.S. and therefore does not place as great a focus on fracture flow in such an environment. Temperature effects in near-field are important. Vitrified waste may reach temp. of 250 C in first ten years. Engineered barriers will be used (bentonite). Regarding Engineered Barrier System (EBS), aluminum analog of apatite may be used in EBS backfill for near-field retardation; optimization of EBS.

E. Bernard Poty (CREGU)
   1. Clay stability (smectites), their surface properties and exchange capacities; interaction with fluids and organics.
   2. Formation and migration of gases - A) experimental approach: expulsion of C02 in clay sediment in near-field; increasing temperature causes release of N2 and H2 gas from NH4+ smectites, but reaction may not be kinetically reversible; evolution of chemistry of the two phases; radiolysis. B) numerical approach.
   3. Actinide solubility - Tc ;and U solubility studies for France are being done at ORNL.
   4. Chemistry of backfill interactions

F. Ardyth Simmons (DOE) - Some topics of interest to the U.S. which could be discussed in more detail for potential collaboration include transport of radionuclides and fission products under redox conditions at Oklo, Tc solubility and speciation in the waste package environment, effect of radiolysis on redox-conditions and- canister corrosion, existence of and consistency of thermodynamic data, waste package corrosion, cement degradation, temperature effects on near-field hydro-geochemistry, mechanistic understanding of sorption from both an experimental and a modeling approach.

SPECIFIC AREAS OF INTEREST TO PURSUE FOR COLLABORATION BETWEEN U.S. AND FRENCH PROGRAMS: (These are grouped with the first six being of higher priority than the last five)

1. ***Title:*** **Paleocirculation (over last million years) in fractured media using isotopic systems**

Description: The only physical record of past circulation of ground water through a fractured rock mass is contained within low-temperature minerals that were deposited from or equilibrated with the circulating water. Numerical dating (U-series and C-14) will be used to establish a time framework of past fluid flow for the past 500,000 years. Compositions of the heavy, radiogenic isotope systems (Sr, Nd, and Pb) will directly reflect those of the source waters from which the fracture minerals precipitated. Carbon isotopes provide a climatic signal and oxygen isotopes will constrain temperatures of formation. Combined, the radiogenic and stable isotope systems will provide key data for understanding the origin and evolution of ground water in a fractured media.
French Contact: Bernard Poty (CREGU)
US Contact: Zell Peterman (USGS)
YMP Interest: The origins of hydrogenic fracture minerals in the rock mass at Yucca Mountain continue to be subjected to multiple interpretations. Application of the combined isotopic and geochronological approach to similar hydrogenic minerals at a French site will further demonstrate the usefulness and will add to the credibility of this approach at Yucca Mountain.
French Interest: The importance of recent circulations of aqueous solutions in fractured hard rocks is a matter of debate and should be understood for the future evolution of a repository.
Level of effort: This would be a cooperative effort involving scientists from the USGS and from appropriate French organizations. Experiment design, sample collections, and interpretations would be completed jointly. Analytical data will be gathered in the Yucca Mountain Project Branch (USGS) isotope laboratories in Denver, Colorado, and in France (CREGU, CEA). Exchange of scientists in all phases of the study would be desirable.
Duration: 3 years
Funding: U.S. ($100k/yr), France ($100k/yr)

2. ***Title:*** **Mechanistic sorption modeling; quantification of uncertainties**

Description: The approach to modeling sorption is one faced by all repository programs. Whether to use a Kd approach or mechanistic models, e.g. triple layer, double layer, ion exchange, etc.) and how various modeling approaches introduce uncertainty into performance assessments is a major question. We would investigate the use of parallel processing in combining speciation and transport codes for a prediction of radionuclide retardation. In applying retardation processes, we would consider the sensitivities of using specific mechanistic modeling approaches and the degree to which they affect repository performance.
French Contact: CEA (DCC)
US Contact: Malcolm Siegel (SNL)
French & YMP Interest: Representation of sorption processes in performance assessments
Duration: 3 years
Funding: $900k ($150k each, U.S. and France per year)

3. Title: **Colloid transport:**

1. **As a function of water saturation**
2. **As a function of electrical fields**
3. **As a function of gas formation and migration**

1. As a function of water saturation

Description: Current conceptual and mathematical models for colloid transport in subsurface environments neglect sorption onto gas-water interfaces. Recent research results have demonstrated that colloids strongly partition into gas-water interfaces in partially saturated and unsaturated media. Static gas-water interfaces behaving as a sorbent phase strongly retard the transport of colloids. However, mobile gas-water interfaces serving as carriers effectively enhance transport of sorbed particles. If radioactive colloids are preferentially sorbed onto gas water interfaces in the vicinity of waste disposal, it is conceivable that either retardation or enhanced transport of these particles will occur. In the first case, sorption of radioactive colloids onto relatively static gas-water interfaces would enhance their retardation. These effects may be especially significant when water films are thin, since much greater shear stresses would be required during movement- and since colloids would strongly interact with both gas-water and water-solid interfaces. In this case the thickness of water-film is critical. In the second case, radioactive particles may be efficiently transported upwards via buoyant gas bubbles. Transport of radioactive colloids could also be facilitated with a continuous flowing gas phase. Both of these modes of transport may be potentially effective at bringing radionuclides to surface environments. The problem in the second case is that we do not have a clear understanding of the dynamics of the gas-water interface. Therefore, research on colloid transport related to gas formation and migration is important. Proposed initial activities: (A) Quasi-static laboratory experiments involving exposure of colloids suspended in solution to gas-water interfaces under conditions representative of those anticipated in the field in solution chemistry, temperature, pressure, and colloid type. These experiments need to be done in batch suspensions, fracture micromodels, and in columns. (B) Dynamic, flow-through experiments will include a moving gas phase through a quasi-static aqueous phase in colloid-enriched suspensions, and unsaturated water flow with a static gas phase. Experiments will be conducted in both fracture micromodels and columns. Bubble-size, gas generation rate, film thickness, interfacial area, transport rate, and solid phase influences will be considered.
French Contact: Joël Billiotte (CGI)
US Contact: Jiamin Wan (LBNL)
French & YMP Interest: Colloid transport of radionuclides must be understood for performance assessments
Duration: 2 years
Funding: $40Ok

2. As a function of electrical fields

Description: Colloid movement is affected by electrical fields: a) natural telluric fields; b) artificial fields created by spontaneous polarization induced either by metallic parts in underground structures and their accesses or by the existence of metallic minerals in the host rock. Numerical modeling, physical modeling, and field measurements are required.
French Contact: Joël Billiotte (CGI)
US Contact: Ines Triay (LANL)
French & YMP Interest: Colloid transport can take place without fluid flow when there are continuous paths of fluid films and/or some clays.
Duration: 3 years
Funding: $600k

3. As a function of gas formation and migration

Description: (combined with function of water saturation)
French Contact: CREGU
US Contact: Jiamin Wan (LBNL)
French & YMP Interest: Colloid transport of radionuclides may be significant to performance assessment.
Duration: 2 years
Funding: $400k

4. Title: **Optimization of Engineered Barrier System (EBS)**

1. **Chemical retardation within EBS**
2. **Stability of clays and effect on radionuclide retardation**

1. Chemical retardation within EBS

Description: Chemical retardation within EBS. Backfill material in the case of fractured environments may be used to establish a first containment barrier for radionuclides. It is suggested that the retarding properties of the clay backfill material be optimized by introducing chemical substances which should delay or even stop the process. Aluminum phosphate is proposed to perform this role in radionuclide retardation. Thus, the stability conditions of these minerals should be studied.
French Contact: Maurice Pagel (CREGU)
US Contact: Willis Clarke (LLNL)
French & YMP Interest: chemical performance of artificial barrier
Duration:
Funding: ANDRA, CEA, CEU

2. Stability of clays and effect on radionuclide retardatior

Description: Stability of clays and effect on radionuclide retardation. Clays are minerals of major interest in the near-field environment for their retention properties. Their exchange capacities, evolution with temperature, and composition of the liquids at equilibrium are not well enough known. Surface properties, e.g. specific surface, size, and sorting properties should be studied in order to model their radionuclide retardation properties.
French Contact: Maurice Pagel, Michel Cathelineau (CREGU)
US Contact: David Bish (LANL)
YMP Interest: Obtaining information on Boom Clay at Mol and much that has been done there
French Interest: French interest: important for clay repository; useful for backfill in granite.
Funding: France, 600k

5. Title: **Technetium solubility and speciation**

Description: Tc(IV) is very insoluble in a reducing environment. If a reducing environment can be maintained near the waste package for a significant period of time, Tc may be retarded. Conduct experiments on Tc solubility and speciation under chemical conditions likely to be present near the waste package.
French Contact: Chinh Nguyen (CREGU-ORNL)
US Contact: David Clark (LANL)- ongoing in FY95
French & YMP Interest: Total system performance assessment
Duration: 2 years
Funding: $200k U.S., $200k France

6. Title: **In situ tracers to characterize potential transport of radionuclides**

Description: (See description in Group 2 for in situ experiments - use a combination of sorbing and non-sorbing conservative and radioactive (short-lived) tracers, as well as surrogates for radioactive tracers
French Contact: P. Touchoat (CEA/DCC) / C. Nguyen (CREGU)
US Contact: John Apps (LBNL) / Ines Triay (LANL)
French & YMP Interest: Understanding of field-scale transport in fractured, heterogeneous media, both saturated and unsaturated
Duration: 5-10 years
Funding: $350k each, U.S. and France per year

7. Title: **Interactions of cementitious materials and near-field environment**

Description: Varied uses of cementitious materials (having a high pH) for grouting, backfilling, etc., can induce reactions on the mineral environment and on canisters in the presence of the aqueous phase. Conduct experiments and simulations to predict changes in water chemistry induced by cement degradation and potential effects on radionuclide retardation.
French Contact: R. Struillou (CEA/DCC/CGI)
US Contact: Annemarie Meike (LLNL)
French & YMP Interest: High pH cement waters would adversely affect radionuclide retardation
Duration: 2 years
Funding: $500k ($125k each U.S. and French per year)

8. Title: **Radiation-induced redox processes at Oklo**

Description: Radiolysis at Oklo has been proven through observations of H2 and 02 in fluid inclusions. Laboratory experiments as well as certain observations in uranium deposits tend to demonstrate that radiolysis leads to oxidation. At Oklo there is evidence that the phenomenon led to strong reducing conditions. The redox situation must be known to understand the mobility of fission elements.
French Contact: CREGU
US Contact: Robert Levich (DOE)
French & YMP Interest: Understand mobility of both radionuclides and fission elements. Please see group 3 discussion. We are interested for the same reasons.
Duration: _____
Funding: _____

9. Title: **Formation and migration of gases (corrosion-induced, radiolytic, etc.)**

Description: In the near-field, gases may be formed through several processes: organic matter maturation (C02 and CH4); clay transformation (H2, N2, NH4); radiolysis (H2, 02). Their formation should be studied through both experimental and numerical approaches. Numerical modeling would help in the prediction of aqueous immiscibility and pressures. Equations of state should be developed for the system C02 - N2 - H2 - 02 - H20 - salts. The chemical evolution of the liquid phase (pH and equilibrium with minerals) should be studied as a consequence of immiscibility.
French Contact: Patrick Landais, Michel Cathelineau, Dean Dubessy (CEA/DCC)
US Contact: Arend Meijer (LANL)
French & YMP Interest: potential of gas pressure buildup in creating mechanical instabilities
Duration: 2 years (1 year experiments, 1 year modeling)
Funding: $200k each, U.S. and French per year

10. Title: **Effect of radiolysis in electrochemical processes of container corrosion**

Description: Study of the consequences of radiolysis on the redox conditions near the container. What variations in corrosion electropotential of container material can be expected from radiolysis? Identification of the cathodic processes of corrosion. Consequences on the corrosion of potential container materials (carbon steel, stainless alloys, etc.)
French Contact: EDF/DER
US Contact: Richard van Konynenberg (LLNL)
French & YMP Interest: Performance assessment of waste
Duration: 2 years
Funding: $150k (6 mo/yr; radiochemist/corrosion scientist)

11. Title: **Temperature effects on near-field hydro-geochemical processes**

Description: The near-field thermal regime, which may attain transient temperatures exceeding 250 C, will have a substantial impact on the distribution and characteristics of minerals composing the host rock. Accelerated alteration under liquid water- or vapor-saturated conditions will change the porosity, permeability, reactive surface area and mechanical properties of the rock. Hydrolysis reactions involving ferrous iron can induce strongly reducing conditions. Clays and zeolites will be altered to different phases with a lower hydration state and specific surface area. Readily exchangeable cationic species will be incorporated into more stable lattice sites of secondary phases. The solubilities of radionuclides in such an environment are likely to be affected strongly. Although it is not presently possible to predict the overall impact of near-field alteration on radionuclide migration, an extensive literature describing field and laboratory observations and thermodynamic data is available which should permit conceptual predictions to be made regarding the mineralogical evolution of the near-field in various host rock environments. Once this evaluation has been completed, initial order of magnitude estimates using various models can be used to refine estimates of radionuclide behavior in this environment. Such computations are important in that they place limits on the source terms of many radionuclides at the near-field/far-field interface, and thereby permit more realistic estimates to be made of the rates of release and flux of long-lived radionouclides into the far-field environment. Subtasks: 1) computer modeling of secondary mineral assemblages and the aqueous flux in the presence of radionuclides at elevated temperatures (100-250 C); 2) comparison of modeled results with field and laboratory studies reported in the literature; 3) estimation of kinetics of mineral alteration from literature and field observations; 4) simulation of mineralogical evaluation of elemental volumes of rock at various distances from the thermal source.
French Contact: Michel Cathelineau (CREGU)
US Contact: John Apps (LBNL)
French & YMP Interest:
Duration: 5 years
Funding: $300k each, U.S. and France per year

Group 5

Technology development in the storage of low to medium level waste

Group Leader: Ann-Marie Meike, (LLNL),
Members: Ken Flower (UCB), Per Petterson (UCB), Gilles Rousset (Ecole Polytechnique), and Michel Deveughele (CGI)

1. ***Title:*** **Modeling of diffusion of water in multilayers**

2. ***Title:*** **Chemical aspects of water-clay interaction**

3. ***Title:*** **Microbial ecology in clay environments**

4. ***Title:*** **Waste package materials**

I. FLOW AND TRANSPORT PROCESSES

A. Colloidal and Multiphase Transport

Colloid transport of radionuclides under multiphase condition plays an important role in performance assessment of Yucca Mountain and other nuclear waste repositories. The colloid transport processes may be controlled by liquid saturation, electrical fields, gas formation and migration, and some other factors. However, our understanding of colloidal multiphase transport is very limited due to few studies conducted in this area.

Project Descriptions

To study the colloidal multiphase behavior of transport in porous and fractured media, we will perform both laboratory and theoretical studies, and the following tasks are proposed.

1. Laboratory micro model study and numerical simulations to understand the colloidal transport including diffusion into matrix and gas bubble transport.
2. Study of multiphase behavior of fracture flow: laboratory study in single fractures, surface geometry characterization, numerical simulation, upscaling to fracture network by numerical simulation.
3. Quasi-static laboratory experiments involving exposure of colloids suspended in solution to gas-water interfaces under conditions representative of those anticipated in the field in solution chemistry, temperature, pressure, and colloid type. These experiments need to be done in batch suspensions, fracture micromodels, and in columns.
4. Dynamic, flow-through experiments will include a moving gas phase through a quasi-static aqueous phase in colloid-enriched suspensions, and unsaturated water flow with a static gas phase. Experiments will be conducted in both fracture micromodels and columns. Bubble-size, gas generation rate, film thickness, interfacial area, transport rate, and solid phase influences will be considered

French Contacts: Joël Billiotte (École des Mines) [CGI]/ CREGU
U.S. Contacts: Karsten Pruess, Jiamin Wan (LBNL) / Ines Triay (LANL)
Duration: 3 years
Funding: $1400K per year

B. Solubility/Sorption

Summary & Grouping of Proposed Projects

B. Solubility/Sorption

The aqueous phase solubility and sorption on rock surfaces are fundamental mechanisms which govern radionuclide and chemical transport in porous/fractured media. The origins of recent circulations of aqueous solutions in porous/fractured rocks are subject to multiple interpretations and should be understood for the future evolution of Yucca Mountain and other repositories.

Project Descriptions

The numerical dating (U-series and C-14) will be used to establish a time frame of fluid flow for the past 500,000 years. Compositions of the heavy, radiogenic isotope systems will directly reflect those of the source waters. Carbon isotopes will provide a climatic signal, and oxygen isotopes will constrain temperatures of formation.

1. Investigate the use of parallel processing in combining speciation and transport models to predict radionuclide retardation, and consider the sensitivities of specific mechanistic modeling approaches and the degree to which they affect repository performance.
2. Conduct experiments on Tc solubility and speciation under conditions likely to be present near the waste package.

French Contact: Bernard Poty (CREGU) / CEA (DCC) / Chinh Nguyen (CREGU-ORNL)
U.S. Contact: Zell Peterman (USGS) / Malcolm Sielgel (SNL) / David Clark (LANL)
Duration: 3 years
Fundin:g $1700K per year

C. Heterogeneous Media

Large heterogeneous systems are commonly encountered when studying flow and transport related to nuclear waste repository sites. Such systems are difficult to model and the related uncertainties are difficult to quantify. In an effort to better understand these systems, we are (1) exploring ways to improve our modeling capabilities and (2) using *in situ* tracers to characterize the potential transport of radionuclides in these media. The information from these projects will help in the design of field tests for site characterization, repository design, performance prediction, and demonstration of regulatory compliance.

Project Descriptions

1. Explore alternative conceptualizations and representations of heterogeneity.
2. Improve numerical methods appropriate to different conceptualization of heterogeneous systems, including more efficient algorithms, improved space and time discretization schemes.
3. Develop methods of dealing with uncertainty, especially for safety analysis, and, to demonstrate the capabilities of the model, we will apply the model to appropriate sets of field data.
4. Use sorbing and nonsorbing conservative and radioactive (short-lived) tracers as well as surrogate tracers in field experiments to characterize the field-scale transport of radionuclides in saturated and unsaturated heterogeneous media.

French Contact: Emmanuel Ledoux (École des Mines) / P. Touhoat (CEA/DCC) / C. Nguyen (CREGU)
U.S. Contact: Yvonne Tsang, John Apps (LBNL) / Ines Triay (LANL)
Duration: 5–10 years
Funding: $1500K per year

Summary & Grouping of Proposed Projects

II. COUPLED PROCESS STUDIES

A. Thermo-Mechanical-Hydrological Behavior of Single Fractures

The subsurface environment for waste repositories is subject to thermo-mechanical-hydrological combining effects. Through model development and laboratory tests, we are studying the thermo-mechanical and hydrological coupled behavior of rocks of interest to both groups.

Project Descriptions:

To understand the behavior and coupled effects of stress, temperature, and water content on rock deformation and fluid flow, the following studies are proposed.

1. Thermo-mechanical behavior of porous/fractured rocks, permeability measurement and variation versus stress and temperature for argillaceous, partially saturated, and low permeability rocks
2. The constitutive law for fractures and the relationship between geophysical and hydrologic properties of fractures.
3. Time effects on mechanical response and permeability, subcritical crack growth, and water content and chemistry.
4. Flow and transport in fracures under coupled thermo-mechanical-hydrological effects, and two-phase flow behavior studies

French Contacts: Joël Billiotte (École des Mines) / Yves Leroy (École Polytechnique) / Jean-Paul Tisot (Laboratoire de Geomecanique) / Patrick Lebon
U.S. Contacts: Larry Myer, Jane Long (LBNL) / Zell Peterman (USGS)
Duration: 3–5 year duration
Funding: $1000K per

B. Thermo-Mechanical-Hydrological Block Tests

Through model development and field tests, we are studying thermally induced coupled processes.

Project Descriptions:

This project consists of laboratory, field and modeling studies of thermally induced coupled processes.

1. Laboratory tests of thermal processes.
2. Field tests including heated room tests.
3. Block test modeling studies including near-field modeling and far-field modeling.

Summary & Grouping of Proposed Projects

C. Field Studies of Excavation Effects

These studies measure the extent of damage induced by the excavation process/thermal load in low matrix permeability rock

Project Descriptions:

For disturbed zone assessments relevant to both the French and U.S. programs, the following tasks are proposed.

1. Using special probes for local permeability measurements near excavation wall.
2. Using geophysical measurements in conjunction with permeability measurements.
3. Developing correlations between geophysical and hydrologic measurements.
4. Developing predictive tools (analytic or numerical) for evolution of damage with time (temperature and stress state).
5. Bench marking with laboratory experimental results.

French Contact: Jean-Paul Tisot (Laboratoire de Geomecanique)
U.S. Contact: Larry Myer (LBNL) / Larry Costin (SNL) / William Lin (LLNL)
Duration: initial testing of 2 years, followed by longer term testing for thermal effect
Funding: $2000K per year

Summary & Grouping of Proposed Projects

III. CHARACTERIZATION OF FRACTURED/FAULTED ROCKS

A. Investigation of Geometry, 3-D Models, Tectonic Effects of Fracture Networks and Major Faults

Model development, testing and eveluation are among important procedures in characterizing fracture system morphology and geometry and the effects of tectonic activity and fault proximity for the area near a repository.

Project descriptions:

Develop and test conceptual models that characterize features such as cementation, fracture, connectivity, alteration, extensional features, and fracture intersections using the data from sites in France and the U.S.

1. Build 3-D models of fracture system genesis to predict 3-D morphology and geometry.
2. Develop mathematical models for hydrologic respones to tectonic activities to study tectonic effects on hydrology and over-pressure near a repository and fault proximity and the effects of earthquakes on repository integrity.
3. Collaborate on developing techniques for imaging fractures and heterogeneities in the midscale near a repository.

French Contact: Bernard Mouroux (ANDRA) / Jean-Michel Le Cléac'h, Roger Cojean (École des Mines) / Michel Colchen, Razack (Poitiers Univ.) / Pierre Godefroy
U.S. Contact: Jane Long, Ernie Majer, Larry Myer (LBNL), Chris Fridrich, Ed Kwicklis, Rick Spengler (USGS) / Frank Tsai (M&O) / Francois Heuze (LLNL)
Duration: 3 years
Funding: $1300–1450K per year

B. Field Testing Methodology Studies at a Prototype Site for Fractured Rocks (Raymond, CA)

The rock mass at the Raymond Field Site is fractured granite. The site will be used to develop techniques and instrumentation for both the Yucca Mountain and the French fractured sites.

Projects Descriptions:

1. Conduct hydrologic and tracer tests.
2. Perform modeling studies to interpret the field test and to derive effective values for the hydrologic and transport parameters.

French Contact: Roger Cojean, Emmaneul Ladoux (École des Mines) / Jean-Paul Tisot (Laboratoire de Geomecanique)
U.S. Contact: Kenzi Karasaki (LBNL)
Duration: 4 years
Funding: $1200K per year

Summary & Grouping of Proposed Projects

C. Testing in Underground Laboratories

With direct application to both the French and U.S. fractured rock programs, studies of the hydromechanical behavior of fractures wlii be conducted utilizing laboratory measurements and theoretical models.

Project Descriptions:

In this task we will design and develop methodology and instrumentation for large scale underground testing.

1. Large scale permeability tests and tracer tests.
2. Mechanical stability studies.
3. Thermal and scale effects.
4. Fracture and fast path characterization.
5. Water age dating and groundwater travel time evaluation.
6. Coupled thermal-mechanical-hydrologic effects.
   a) Heated Room Test
   b) Block Tests
   c) Modeling

French Contact: Emmaneul Ladoux (CIG) / Roger Cojean (CGI) / Jean-Paul Tisot (Laboratoire de Geomecanique)
U.S. Contact: Larry Myer (LBNL) / Paul Witherspoon (UCB)
Duration: 3–5 years
Funding: $1500K per year

Summary & Grouping of Proposed Projects

IV. NATURAL ANALOG STUDIES

A. Investigation of Natural Analogs for Flow and Transport

Natural analog sites allow investigation of features and processes likely to be encountered at a repository site.

Project Descriptions:

The previously studied analog sites will be used to see if geologic features, which dominate flow and transport, can be identified with geophysical methods.

1. Validate the geochemical models EQ3 and EQ6 using data from Taupo volcanic zone studies.
2. Hold a workshop to determine if other types of sites should be examined, for example, sites that show radionuclide migration from U.S. nuclear tests (NTS) or the natural migration of radionuclides in crystalline rocks.

French Contact: Patrick Lebon (ANDRA) / Michael Colchen, Razack (Poitiers Univ.) / Jacques Tamborini (IAEA, Vienna) / Emmanuel Ledoux (École des Mines)
U.S. Contact: Jane Long. Ernie Majer (LBNL) / Dwight Hoxie (USGS) / Anne Marie Meike (LLNL) / John Stuckless (DOE) / Don DePaolo (UCB/LBNL)
Duration: 3–5 years
Funding: $400K per year

B. Cooperative Studies on Oklo–A Natural Nuclear Waste Repository

The Oklo site is the only natural analog of nuclear waste disposal with long-term data. We can use our study of this site to develop confidence in the feasibility studies of safe geologic disposal and ensure that all relevant process are included.

Project Descriptions:

Studies at Oklo are an on-going research program under the coordination of CEA. A joint French U.S. effort would focus on long-term issues consistent with the intent of the second phase. The following tasks are proposed:

1. Document the release and transport of selected radionuclides in the natural environment of Oklo,
2. Investigate far-field isotopic geochemistry to learn about radionuclide transport
3. Conduct a detailed medium-scale study with emphasis on processes relevant to waste repositories.
4. Study the radiation-induced redox process (strong reducing conditions have been observed at Oklo).

French Contact: Emmanuel Ledoux (École des Mines) / Alain Regent (CEA) / CREGU
U.S. Contact: Chin-Fu Tsang (LBNL) / Robert Levich (DOE)
Duration: 3–4 years
Funding $900K per year

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