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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT
June 10, 1994

SUBJECT: First North American Rock Mechanics (NARM) Symposium (20-5702-152)

DATE AND PLACE: June 1-3, 1994, Austin, Texas

AUTHOR: W. Patrick

PERSONS PRESENT:

Approximately 360 technical professionals, professors, researchers, and students representing all areas of civil, mining, petroleum, and related industries. No attendance list was available.

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PURPOSE:

The 1st North American Rock Mechanics (NARM) Symposium, which was held in Austin, Texas, June 1-3, 1994, was introduced this year to regionally focus the ongoing series of symposia that are co-sponsored by the International Society for Rock Mechanics (ISRM) and the national rock mechanics organizations, including the US National Committee on Rock Mechanics (USNC/RM). In even numbered years, regionally sponsored symposia will be conducted; in odd numbered years the ISRM will host the global conferences. The 2nd NARM will be held in Montreal (see attached announcement).

I attended NARM as a professional development activity. The purpose of this activity was three-fold, to:

- Interact with professionals in the broad field of rock mechanics, my technical area of expertise;

- Learn of some of the most recent (largely unpublished) advances in this important field, many of which are highly relevant to the repository programs of the U.S., as well as Sweden and other foreign governments; and

- Contact technical program managers in key North American industries and government agencies that are working in areas where technical resources similar to those resident in the CNWRA are needed.

The modes of presentation at the symposium included keynote addresses, formal technical presentations, panel discussions, technical exhibits, and poster sessions where direct interaction with technical staff was possible (see attached Program). Given the press of other business, I was not able to participate in any of the pre- or post-symposium workshops or short courses that were offered.

SUMMARY OF PERTINENT POINTS AND ACTIVITIES:

A. ROCK MECHANICS SYMPOSIUM

1. A. (Skip) Hendron (U of Illinois) spoke to a plenary session of the NARM on applications of rock engineering to civil engineering projects. In each case study, one or more of several factors were important: rock mass modulus, shear strength, permeability, *in situ* stresses, and excavation

methods [including use of Tunnel Boring Machines (TBM)]. Hendron elucidated a technique for comparing new projects with prior projects in which failure occurred, using the historic Viaont, Italy slope failure as an example. Detailed calculations of the Viaont failure provided great insight into how sensitive performance was to changes in particular conditions and parameters (in this case, change in water level at the base of the slope). Application of this knowledge to a hydroelectric project on the Columbia River led the engineers to avoid undue reliance on calculations of complex behavior and, instead, rely on a design which produced no change in the critical parameters and conditions.

2. A. B. Maldonado (consulting engineer) presented a key-note lecture on a 58 km tunnel driven through highly complex ground which included more than a dozen different hard and soft rocks and soils. Among the problems encountered was 17,000 L/s inflow (the tunnel face looked like a waterfall in several sections). He conveyed the philosophy that "big jobs are a university," since they invariably introduce problems far beyond those seen in smaller or more routine projects. Nonetheless, project owners often will not allow the necessary studies until significant risks (i.e. threats to success of project) are encountered. He highlighted the need for and responsibility of engineers to identify and focus management/owner attention on those areas that are most likely to cause problems.

3. E. Lindquist (U.C.-Berkeley) spoke on the strength and deformation properties of a physical model melange which they are using to evaluate projects in these formations. Melange formations of interest are typically represented by blocks of strong, stiff rock (varying from inches to mountain size) in a matrix of weaker, softer rock. Although these are common throughout the world, they are most frequently encountered at continental margins and in mountainous regions. These formations are most difficult to address in design of dams and tunnels.

   Lindquist used a bentonite portland cement matrix with sand portland cement blocks (clasts) cast into the matrix; these casting were cored to allow parametric evaluation of key factors. Some casting included wax layers to simulate slickensides. Key finding were that (i) cohesion decreases about four fold when the percentage of the sample that is matrix decreases from 75% to 25%; (ii) friction increased inversely (from 30 to 60°) with decreases in matrix composition; (iii) no significant orientation effects were seen; and (iv) failures tended to be along interfaces rather than through the weak matrix material. In addition, changes in modulus with matrix composition were most pronounced when the clasts were at high angles to the direction of loading; no effect was observed when clast orientation was horizontal.

4. E. Medley (U.C.-Berkeley) described a technique for estimating block volumetric proportions of melanges and similar Block-in-Matrix Rocks (BIMROCKS). His study of the Franciscan Formation in northern California suggests this approach to treating melanges <u>may</u> be useful in evaluating strength and deformability of faulted, brecciated, and/or hydrothermally altered zones. Relative frequency of clast diameter normalized to the square root of area mapped (i.e. $d/A^{\frac{1}{2}}$) indicates scale independence.

Medley applied mathematical principles of stereology (which have been developed and widely used in the life sciences) to relate 1, 2, and 3 dimensional characterizations of melange assemblages (e.g. using 1-D to estimate 3-D).

5. C. Wideman (USBM-Spokane) presented the results of an evaluation of the Lucky Friday Mine seismic (rockburst) source term. He found considerable difficulty in applying current earthquake seismic source methods to mine rock bursts. He described the PC-based data acquisition and source solution calculations developed for use in this mining district. Because of the typical orientation of mine openings, instruments are often located along nodal planes, making it difficult even to resolve whether the sense of motions is dilational or compressional. Wideman gave one example which could be interpreted as right-lateral or left-lateral, depending on which transducers were selected for calculating the source term.

6. A. Squelch (CSIR) proffered a design rationale which was aimed at bringing a measure of consistency in underground design. Diverse underground conditions have led to nearly 140 different designs and support systems. Still, they are faced with the statistic that 50% of all accidents and fatalities in these mines are due to rock falls and bursts. The design rationale employed both stress (support) and energy (absorption of burst energy) criteria to standardize design bases. They found it was fruitless to focus on design, *per se*, due to the highly variable rock properties, stresses, etc.

   Although their initial application of the design rationale/criteria met with good success, rock fallout between support units indicates that an additional criterion is needed (modelling is in progress to address this). They obtained the somewhat counter-intuitive result that "packs" which are too strong and/or too stiff (it was not clear to me which was the deciding factor) actually induced failure of the roof and floor rocks. They concluded that packs need to yield below the rock damage threshold. Although he did not address it in his presentation, the observed phenomenon and support needs appear to be analogous to those that led to development of the so-called New Austrian Tunnelling Method (NATM) a number of years ago.

7. A. Squelch also gave an overview of new developments in South African mining (L. Wojno's paper) for precious metals at 2.5-3.5 km, where 40 MPa mining-induced stresses are superposed on *in situ* stresses of 150-200 MPa. Investigations have focused on use of yielding tendons to accommodate yield forces ≥100 kN with dynamic loads of 50 kN, over displacements up to 0.5m, with about 25kJ of work done during displacement. A novel "cone bolt" approach is used to provide yielding support in areas prone to large displacements and/or dynamic loads. This system has been tested under dynamic loads and found to be very effective. By coupling this system with a thin (e.g. 1½-2mm thick) flexible fiber-reinforced acrylic coating on rock surfaces (to keep materials from unravelling between bolts), they are able to provide support to even the most difficult rock formations.

8. A.M. Linkov (Russian) gave the 1994 Schlumberger lecture on "Rock Bursts & Stability of Rock Masses." This lecture will be published in the International Journal of Rock Mechanics and Mining Science (IJRMMS). The lecture summarized a series of papers Linkov published between 1977 and 1992 dealing with models for stress-strain and stress-displacement relationships relating to failure and post-failure strain-softening phenomena. Linkov also referred to recent work by Soloman on probabilistic approaches to rock properties and rock bursting.

9. R. Wang (U. of Arizona) described recent work on coupled mechanical loading and flow experiments in tuff which has been conducted with J. Kemeny. They used Apache Leap tuff for axial and lateral flow tests, where direction is expressed with respect to loading axis. Axial flow tests were performed under multiple cycles of uniaxial and triaxial loads, with permeability measured at various loads. We discussed the need to apply acoustic emissions techniques to check for onset of fracturing. This would help resolve his hypothesis that permeability increases are associated with the coalescence of microfractures.

10. Y. Zhong (U.C.-Berkeley) reported on a three-phase study to: characterize natural fractures using fractals, reproduce simulated networks based on fractals, and model flow through such networks. He used the "Menger Sponge" to represent 3-D fracture networks, and modelled flow and the diffusion fronts using finite difference methods. There was considerable confusion (on the part of both the author and audience) concerning the fractal dimension of the fracture network vs the fractal dimension of surface roughness.

11. C. Renshaw (Stanford) described his work on physically based models of rock fracture. The models consist of brittle coatings on deformable base materials, which are deformed to create fractures, and numerical fracture mechanics models. The general approach was to use such models to (i) understand and simulate the evolution of fracture systems, (ii) examine heterogeneities and their effects (e.g., clusters), (iii) study "coincident formation" of fractures and their causes. He also referred to the multiple-borehole interference tests of Paul Shay (USGS) in Vermont granite which are coordinated with this study.

12. W. Miller (WES) conducted a study of joint compliance which was motivated by development of a simulant for Topopah Spring Tuff under a Sandia National Laboratories (SNL) contract. Although this work was terminated before completion, Miller was able to simulate the behavior of the joint using the discontinuous deformation analysis (DDA) technique as fracture "roughness" (i.e., different gaps/lengths of elements near fracture). There are fundamental questions concerning the appropriateness/legitimacy of this approach, since no real constitutive law was developed for the joint. Although the technique does produce total fracture closure, it appears to work only under normal load.

13. S-M. Hsiung (CNWRA) presented the results of his work at CNWRA on pseudo-static and dynamic loading of rock joints. Since this paper is readily available, no further discussion is provided on it here. Questions were

raised by a representative of the Norwegian Geotechnical Institute (NGI) and another individual (who failed to identify himself) regarding (i) which formulation of the Barton-Bandis model was used (a more recent version was said to be available but the individual could not provide a reference for it); and (ii) whether the model was used "out of context" in what the NGI representative referred to as a mismatched condition.

14. G. Archambault (U. of Quebec) spoke on the mechanics of progressive shear failure. He noted that both homogeneous and heterogeneous masses exhibit the same anastomosed fracture pattern in the fourth phase (residual) shear failure. This pattern is evident from micro- to mega-scale. His results warrant consideration in interpretations of structural geological studies by CNWRA. The most important aspect of this work is that it can be used to explain how complex fracture patterns can develop under a single ongoing shear process, as opposed to the usual interpretations of "globally" varying state of stress causing the different fracture patterns.

15. M. Cooke (Stanford) evaluated development of bedding plane faults by treating interfaces between bedded shata in a frictional mode. The model expresses (i) bedding faults, (ii) fractures due to curvature of the beds, and (iii) joints near bedding fault tips. Cooke used a boundary element method to simulate deformation of two elastic layers.

16. B.T. Brady (USBM) spoke from a theoretical physics perspective on development of a thermodynamic basis for scaling laws. He invoked the theory of universality, which suggests that at the "critical point" (i.e., where phase or state changes occur) the behavior of the material is "significantly independent" of the detailed properties and micro-physics of the system. He defined on "order parameter" for common systems (magnetics, liquid/gas, etc.) and invoked "gauge invariances" (similar to those that explain general and special relativity and Newton's laws) and their associated symmetries. Brady treated brittle fracture of rock as a "tricritical" phenomenon associated with solid, solid plus microfracture, solid plus macrofracture states.

17. C. Francke (Westinghouse/WIPP) described the results of ongoing roof fall monitoring and modelling at WIPP. He provided an overview of the purpose of WIPP and technical rationale (e.g., geologic stability, hydrogeologic properties, thermal properties, creep, etc.) for selection of salt as a disposal medium. Long-term behavior of rooms and failures are governed by creep of halite, as affected by seams which define "beams" in the roof and floor. Formation, geometry, and relative motions on seams and fractures appear to be independent of room size and pillar dimensions; these factors appear to only affect the timing of the motions and onset of failures. One major (700T) roof fall has occurred to date at WIPP and another is pending. As is often the case in such large DOE projects, this work by the Management and Operating Contractor does not appear to be integrated with the SNL studies (which were presented in other sessions), and vice versa.

18. M. Gutierrez (NGI) presented a very preliminary micromechanical model of the hydromechanical behavior of a single fracture, which has been implemented using UDEC. Normal and sheer stresses are applied, as are

inlet and outlet hydraulic pressures; fracture surfaces are digitized as straight-line segments; and a Mohr-Coloumb model with dilation and parallel plate flow model are deployed. Not much work appears to have been done to date with the hydrology portion of the model. Furthermore, changes in joint properties as shear progresses were not addressed. Work has not progressed to include comparison with laboratory or other experimental results.

19. M. Scoble (McGill U.) examined competitiveness of the mining industry in deep hardrock mines. His focus was on integration of rock mechanics, mining, geology, automation, and information systems to "radically improve" mining industry competitiveness. The impetus is that (i) there have been few new finds and these are deep, (ii) there are environmental and political constraints, (iii) productivity and cost factors have been unfavorable for many years, (iv) we have an aging work force, and (v) foreign competition continues to increase. Ongoing research should continue and increase in areas such as (i) mine-induced seismicity and its control, (ii) monitoring seismicity and rock-mechanical behavior broadly, (iii) modelling and mine design, (iv) ground-control systems, (v) remote and automated mining, (vi) mining methods and machine design, (vii) sensory perception to support automation, and (viii) information processing and interpretation. INCO has advanced to "telemining": operating underground load-haul-dump units from surface. As a demonstration, one man on the stage of a recent Canadian conference operated two mining machines on two separate levels of a remote mine via satellite. This demonstration advanced INCO to the proof-in-practice stage of an ongoing effort to remove miners from underground. Finnish industry has an "intelligent mine" initiative well underway, too.

20. J.N. van der Merwe (Sasol Coal) provided a South African perspective on geoengineering, stating that there are only two reasons to study rock mechanics: (i) improve safety and (ii) enhance productivity. He emphasized that bridging from theory and research to practical implementation is the critical step; failure here renders all preceding study worthless. Successful application of geoengineering principles in deep South African coal mines has increased extraction to 80-85% and reduced unplanned roof and rib failures by nearly 95%.

They use an S-shaped probability of failure curve where the probability of failure is 0.5 for a Factor of Safety (FS) of 1. Interestingly, an exhaustive study showed that FS=1.6 at p=0.5. Clearly, the strength and/or stress determinations are in error. They have, for their mining situation, concluded that all pillars will fail, it is only a matter of time. Consequently, recent research focuses on time to failure (a concept developed by researchers at the University of Missouri-Rolla 20 years ago, but never fully deployed by US industry) rather than probability of failure, *per se*. At several points, he refocused attention on real problems vs measurable phenomena: for example, the problem is rock bursts, <u>not</u> mine seismicity. He noted that there is a scientific parallel to the Michelangelo's statement that the secret of art is to know how to look.

21. N. Sundin (U. Lulea) described a new boreability model for TBMs which predicts a boreability index, net penetration, and number of shifts to bore the total tunnel, based on basic indices, machine parameters, and qualitative empirical parameters. He recommended using this model not just for prediction, but for monitoring changes in conditions.

22. N. Chandler (AECL) presented the results of recent work on the influence of near- surface faults on *in situ* stresses that was conducted at the Underground Research Laboratory (URL) in the Lac du Bonnet batholith. They have observed that "fracture zones" 1, 2, and 3 are reverse faults with displacements of 1 to 7m. Fracture zone 2 segments the state of stress into two distinctly different regimes in terms of both magnitude and orientation. Chandler used FLAC and UDEC to model a 1.5×2.2 km two-dimensional region of the batholith; imposing a constant-displacement boundary on the problem. Both codes captured the general trends, with FLAC doing somewhat better predicting the magnitudes of dip-direction stresses.

23. D. Yale (Mobil) reported on studies of *in situ* stress in the mid-continent. Focusing on Kansas and northern Oklahoma in oil fields at depths of 3,000-6,500 ft, he used shear wave birefringence to infer microfracture orientation and hence, stress orientation. Hydrofracturing in wells and tiltmeters were used in the field measurements. The work generally confirms Zoback's 1992 worldwide stress mapping results, but indicates the local influence of two faults.

24. F. Djahanguiri (USBM) described recent work on rock fragmentation at the Colorado School of Mines (CSM) experimental mine. Using a carefully designed explosive pattern, they were able to achieve the somewhat conflicting objectives of (i) heavy fragmentation of the ore (for subsequent leaching) and (ii) minimum damage to the wall rock. Interestingly, powder factors were quite high at 1.9-2.5 Kg/T.

25. J. Song (Columbia) presented the results of some very early work on numerical simulation using a Lattice Network Model. The basic lattice geometry comprised individual masses (representing rock particles) in lattices of six springs, used a maximum strain criterion to define fracture initiation, and treated energy dissipation. Simulated fracture patterns under explosive loads simulating simultaneous, short-period, and long-period delays were found to be fractal; with longer delays giving greater fracturing overall.

26. A special panel session, moderated by J.Long (LBL), was conducted on *in situ* stress and flow in fractures. Key points of the discussion (which, in general, do not reflect a consensus) included (i) changes in stress were argued by some to be important only at "lower" levels, although J-C. Rogier presented an argument that stress "drives" flow in some reservoirs at all stress levels; (ii) state of stress is so highly heterogeneous that drawing inferences on stress-flow relations is speculative; (iii) work at Ekofisk reservoir showed stress controlling permeability, not dominant fracture orientation; (iv) "detailed fracture mapping doesn't help" because only the most conductive fractures are of interest and these are "uniformly" oriented with major stress; (v) stress-permeability

relationships may be different for "clean" joints vs well developed faults, consequently, there is a need to consider fracture morphology; (vi) Golder's work at Espe (Japan?) and Sellafield found that four factors correlate with conductive fractures, none of which is stress; and (vii) relative permeability of fractures vs matrix appears to be important with regard to whether and how stress affects flow.

27. W. Dershowitz (Golder) gave a keynote address on discrete fracture approaches in the petroleum industry. He led off with the statement that the petroleum industry today is where mining and civil engineering rock mechanics were 30 years ago: they are just beginning to recognize and utilize discrete fracture methods in reservoir engineering. About 40% of reservoirs have significant fracture or fault effects. Main areas of interest are multiple porosities, scale effects, hydraulic interference among wells, and propagation of hydraulic fractures to further stimulate wells. He described and discussed five alternative approaches to fracture modeling, together with advantages and disadvantages: (i) dual porosity, (ii) stochastic continuum, (iii) fractal, (iv) percolation theory, and (v) discrete fracture dual porosity. The last of these is preferred, although he noted that the heterogeneous connectivity continuum approach (Intera/ECL Eclipse code) can capture some of these features by introducing "connecting" or preferred flow paths in a finite difference mesh.

28. N. Meehan (Union Pacific) identified the principal rock mechanics issues in petroleum as (i) drilling (borehole stability and rock failure), (ii) horizontal drilling for stimulation of fractured reservoirs, (iii) well bore characterization (interpretation of well bore data), (iv) use of outcrop studies (did not view this favorably because of fractures *per se* are not important from his perspective, it is conductive fractures that are of concern), (v) interference of additional wells; (vi) hydrofracturing (measuring stress, predicting pressure to fracture, tortuosity), and (vii) "geosteering" to track thin (~50 ft) often dipping geological features that are in the producing zone.

29. J. Muralha (U of Lisbon) gave a largely philosophical paper on uncertainty, reliability, and risk in rock-block stability. Noting that uncertainty permeates the most critical aspects of failure modes, media characterization and properties, and driving forces, he further observed that the skewness of common parameter distributions makes means nonconservative. As a first step (if one insists on using a single-value deterministic approach), he recommends using the median of the parameter distribution.

30. S. Blair (LLNL; student UC-Berkeley) is conducting rather basic research on the effect of disorder on rock compressive strength. He is considering variability/disorder on the grain scale and modeling laboratory-scale tests. Disorder is incorporated in his boundary-element model in terms of stress, tensile strength, and lattice variations. Failure is defined via percolation theory (cracks must be continuous throughout a specimen for failure to be predicted). Not surprisingly, his results show that strength

decreases with increasing geometric disorder (i.e., grain size and orientation, independent of individual grain/matrix strengths).

B. U.S. NATIONAL COMMITTEE ON ROCK MECHANICS

Separate discussions were held regarding the current status and future plans for the USNC/RM. Results may be summarized as follows.

1. B. Brady provided an overview, noting that since 1989, the USNC/RM has been an operating unit of the Geotechnical Board of the National Research Council. A special report on Fracture Characterization & Fluid Flow (led by J. Long) was completed this year and will soon be published. Professor H. Einstein (MIT) currently represents the USNC/RM to the ISRM. Neville Cook (U.C.-Berkeley) won the prestigious Leopold Muller award.

2. Peter Smeallie, Executive Officer of Geotechnical Board resigned in May, leaving a void with the ISRM and National Research Council interactions. The latter organization is in the midst of reorganization. There is a great deal of turmoil at this time and there are serious questions regarding whether the interests of the USNC/RM will be well-served under the new organization. We agreed to take a two-pronged approach: (i) proceed actively to become involved in the reorganized Board and associated Commissi n and (ii) evalu te whether it is appropriate to separate representation of the rock mechanics community within the National Research Council from the professional society functions of the USNC/RM.

C. SPECIAL SESSION ON THE NORTH AMERICAN FREE TRADE AGREEMENT (NAFTA)

Given that NARM focuses on the continent of North America, the conference organizers took the opportunity to conduct a special session on NAFTA. Experts from the University of Texas, a local consulting firm specializing in NAFTA, Canada, and Mexico formed a panel to discuss this topic. Key points are summarized below; additional material on NAFTA is contained in the attachments. The general theme was that of addressing change; how we perceive change depends on our knowledge and wisdom regarding such change. The more one knows, the more one sees change as opportunity.

1. Marian E. Swank (President of Swank, Inc. and publisher of NAFTA News) noted that the Department of Commerce and regional seminars are some of best sources of information regarding NAFTA. Her expertise appeared to be limited to Mexico; knowledge of Canadian aspects was poor, naive, and punctuated with generally negative remarks (e.g., she was unaware of the timber, potash, and electrical power trades). Of particular note is that Mexico will, in general, need assistance in financing major projects (e.g., via Import-Export or World Banks). Many infrastructure projects should open up in the months and years ahead, many of which have implications for the rock mechanics community. She emphasized the need for ongoing personal relationships as a basis for business, and use of technical seminars to establish credibility. Engineering and design services are of greatest demand in civil works, municipal services, energy

supply and distribution, etc. She noted that it is most effective to work with a Mexican firm and/or on joint ventures.

2. Michael Charles (ASCE Manager of International Affairs) spoke to temporary entry of professionals under NAFTA. The base load of engineering and consulting work for professionals is $285B/yr in Canada and $146B/yr in Mexico in 1993. There are some restrictions on professional work under NAFTA: principally, one must meet local licensing requirements at state or national level, as appropriate. Provisions are in the law for consideration of *de facto* licensing reciprocity. There are no requirements to establish branch offices to do business in a NAFTA country. Furthermore, there were no changes to immigration requirements: Canadians did not and do not need VISAs, Mexicans did and do need VISAs; requirements for residency did not change.

3. Dougal McCreath (Laurentian University) noted that, being the smallest partner, they are a bit nervous and skeptical of NAFTA. Canada is currently the US's largest trading partner ($200B in goods alone); Ontario alone does more trade with the US than all of Japan.

4. Guillerno Botas Espinosa noted that the key consideration to keep in mind is that both US and Canada write contracts according to Anglo-Saxon law vs the Mexican Roman-Napoleonic Code. Different rights and constraints exist under these two forms of law which can generate a great deal of misunderstanding, mistrust, and hard feelings. As a specific example, contractors and constructors are treated differently under the law in Mexico than individual consultants.

5. Arturo Bello Maldonado spoke as a private consultant, noting both the opportunities and risks of NAFTA. Encouraged focus on bringing capabilities to Mexico which they lack, rather than competing for existing Mexican jobs which they are competent to do themselves. "Mexican pride" spoke, with Maldonado stating that they want to be players in the game, not spectators, and that they don't want "bad boys" on the playing field.

IMPRESSIONS/CONCLUSIONS:

The 1st NARM was well-attended and a success by every measure. Various brochures from exhibitors, conference proceedings, and abstracts of poster sessions are available from the author, for those interested.

PROBLEMS ENCOUNTERED:

None to report.

PENDING ACTIONS AND RECOMMENDATIONS:

1. Medley's approach to melanges in the Franciscan Formation in northern California may be useful in evaluating strength and deformability of faulted, brecciated, and/or hydrothermally altered zones, and should be evaluated further by the Geologic Setting (GS) Element.

2. Conversations with Dr. K-S. Kim (Columbia) indicated that he is pursuing NRC funding for an investigation of the application of probabilistic rock properties in repository design. CNWRA should maintain close contact with NRC and Dr. Kim on this matter, given its potential importance to our reviews of DOE repository designs.

3. Wideman's results on the Lucky Friday Mine seismic source term have potential implications for the CNWRA Seismic Rock Mechanics Project and should be carefully evaluated.

4. The Repository Design, Construction, and Operations (RDCO) Element needs to locate and examine the recent work by Soloman on probabilistic approaches to rock properties and rock bursting, which was referred to by Linkov. This work may appear in Rock Bursts and Stability of Mines, a recently published book.

5. Archambault's approach to interpreting complex fracture patterns in the context of a single ongoing shear process rather than under "globally" varying state of stress warrants consideration in interpretations of structural geology by CNWRA GS staff.

6. The efficacy of the heterogeneous connectivity continuum approach (Intera/ECL Eclipse code) as an alternative to treating discrete fracture effects on flow and transport should be evaluated by the Performance Assessment and Hydrologic Transport (PA&HT) Element.

SIGNATURE:

Wesley C. Patrick

6/10/94

CONCURRENCE:

Director of Administration

Technical Director

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