COMMENTS ON GROUND-WATER
TRAVEL TIME
By
CARL JOHNSON
NEVADA AGENCY FOR NUCLEAR PROJECTS

BEFORE

U.S. NUCLEAR WASTE TECHNICAL
REVIEW BOARD
PANEL ON HYDROGEOLOGY AND GEOCHEMISTRY

MY NAME IS CARL JOHNSON. I AM THE MANAGER OF TECHNICAL PROGRAMS FOR THE NEVADA AGENCY FOR NUCLEAR PROJECTS. THE AGENCY IS RESPONSIBLE FOR THE STATE'S OVERSIGHT OF THE NATIONAL HIGH-LEVEL NUCLEAR WASTE PROGRAM. WE HAVE BEEN INTERESTED IN THE DETERMINATION OF GROUNDWATER TRAVEL TIME AS IT APPLIES TO THE SITING AND LICENSING OF HIGH-LEVEL WASTE REPOSITORIES SINCE THE BEGINNING OF THE WASTE PROGRAM. I PERSONALLY HAVE FOLLOWED THE DEVELOPMENT OF THE CONCEPT AND ITS APPLICATION TO THE REPOSITORY PROGRAM THROUGH REGULATION SINCE THE EARLY 1980'S AND HAVE PROVIDED COMMENTS ON THE SUBJECT ON A NUMBER OF OCCASIONS. MY COMMENTS TODAY WILL FOCUS ON NEVADA'S VIEW OF GROUNDWATER TRAVEL TIME FOR THE DETERMINATION OF SITE SUITABILITY AND THE DOE'S APPROACH TO THE DETERMINATION OF GROUNDWATER TRAVEL TIME FOR USE IN A REPOSITORY APPLICATION.

GROUNDWATER IS THE MOST LIKELY MEANS BY WHICH RADIONUCLIDES WOULD BE TRANSPORTED FROM A GEOLOGIC REPOSITORY TO THE ACCESSIBLE ENVIRONMENT. AS WE HAVE OBSERVED AT YUCCA MOUNTAIN, GAS TRANSPORT MAY ALSO BE A LIKELY MEANS. HENCE, A LONG GROUNDWATER OR GAS FLOW

TRAVEL TIME BETWEEN THE UNDERGROUND FACILITY AND THE ACCESSIBLE ENVIRONMENT IS A HIGHLY FAVORABLE CONDITION FOR WASTE ISOLATION. CONSEQUENTLY, OUR CONFIDENCE IN THE ABILITY OF A GEOLOGIC REPOSITORY TO ISOLATE WASTES IS DIRECTLY DEPENDENT UPON AN UNDERSTANDING OF THE GROUNDWATER AND GAS FLOW BETWEEN THE REPOSITORY AND THE ACCESSIBLE ENVIRONMENT.

THE STATE'S VIEW IS THAT THE GROUNDWATER TRAVEL TIME CRITERION IN NRC REGULATION 10 CFR 60.113 (a)(2) IS A TEST OF THE HYDROGEOLOGIC CHARACTER OF THE SITE FROM THE PERSPECTIVE OF PREEMPLACEMENT RATES OF GROUND-WATER MOVEMENT OR NATURAL TRANSMISSIVITY OF THE SITE. THE INTENT IS TO PROVIDE ASSURANCE THAT THE NATURAL, UNPERTURBED GEOLOGIC ENVIRONMENT IS CAPABLE OF ISOLATING WASTE, INDEPENDENT OF THE ENGINEERED BARRIERS AND THE DISTURBED ZONE. THE CRITERION PROVIDES A QUANTITATIVE MEASURE OF THE SITE'S ABILITY TO MEET THE ENVIRONMENTAL PROTECTION AGENCY'S STANDARDS FOR RADIOACTIVE MATERIALS.

THE DOE GROUNDWATER TRAVEL TIME CRITERION UNDER THE 10 CFR PART 960 SITING GUIDELINES PROVIDES A SIMILAR BUT DIFFERENT TEST OF A SITE'S NATURAL CONDITIONS. THE SITING GUIDELINES PRESENT A SERIES OF CRITERIA WHICH A SITE MUST MEET OR IS LIKELY TO MEET, OR THE SITE MUST BE DEEMED NOT SUITABLE FOR FURTHER CONSIDERATION AS A REPOSITORY. THE GUIDELINES CONTAIN A SITE DISQUALIFYING CONDITION FOR GROUNDWATER TRAVEL TIME--A QUANTIFIABLE MEASURE OF A SITE'S ABILITY TO MEET THE STANDARDS. A SITE SHALL BE DISQUALIFIED IF THE

PRE-WASTE EMPLACEMENT GROUNDWATER TRAVEL TIME ALONG THE FASTEST PATHWAY IS DETERMINED TO BE LESS THAN 1000 YEARS. IF THE TRAVEL TIME IS GREATER THAN 1000 YEARS, A SITE MAY QUALIFY AS A SUITABLE SITE, SUBJECT TO OTHER CRITERIA. IN MY VIEW, THE CRITERION IS CLEAR AND UNAMBIGUOUS. THE SITE EITHER MEETS THE 1000 YEAR THRESHOLD, OR IF IT DOES NOT, [redacted] THE SITE IS DISQUALIFIED.

AT YUCCA MOUNTAIN, PRE-WASTE-EMPLACEMENT UNSATURATED ZONE TRAVEL TIMES ARE VERY CRITICAL TO THE DETERMINATION OF SITE ACCEPTABILITY. MEASUREMENTS OF HYDRAULIC CONDUCTIVITIES AND ESTIMATES OF EFFECTIVE POROSITIES IN THE FRACTURED WELDED TUFFS OF THE UNDERLYING SATURATED ZONE INDICATE THAT TRAVEL TIMES ARE ONLY A FEW HUNDRED YEARS FROM BENEATH THE REPOSITORY AREA TO THE ACCESSIBLE ENVIRONMENT; THEREFORE, FOR THIS SITE TO BE ACCEPTABLE FOR A REPOSITORY, THE UNSATURATED ZONE IS KEY TO MEETING THE 1000 YEAR TRAVEL-TIME CRITERION. IF ALL THE UNSATURATED ZONE FLOW IS RESTRICTED TO MATRIX FLOW, TRAVEL TIMES WILL LIKELY BE LONG, MEASURED IN THOUSANDS OF YEARS. HOWEVER, IF THERE IS FRACTURE FLOW BETWEEN THE DISTURBED ZONE (THE BOUNDARY OF WHICH HAS YET TO BE DETERMINED) AND THE UNDERLYING SATURATED ZONE, TRAVEL TIMES WITHIN THIS ZONE WILL LIKELY BE VERY SHORT, MEASURED IN TERMS OF YEARS OR HUNDREDS OF YEARS. INFORMATION GATHERED TO DATE CONFIRMS THAT TENS OF MILLIONS OF FRACTURES OCCUR WITHIN THE UNSATURATED ZONE OF THE PROPOSED REPOSITORY BLOCK. IT HAS YET TO BE DEMONSTRATED THAT THESE FRACTURES [redacted] DO NOT TRANSMIT WATER. IT IS ALSO POSSIBLE THAT FAULTS

FUNCTION AS WATER CONDUITS, BUT THIS TOO HAS YET TO BE FULLY DETERMINED.

THERE ARE TWO APPROACHES FOR GATHERING INFORMATION TO ASSESS FRACTURE FLOW: DIRECT MEASUREMENT OF HYDRAULIC PROPERTIES, AND GROUNDWATER DATING. DIRECT MEASUREMENT OF PROPERTIES IS DIFFICULT IN COMPLEX, FRACTURED, HETEROGENEOUS CONDITIONS DRIVEN BY PULSED RECHARGE FLUXES. AT YUCCA MOUNTAIN, RELIABLE REPRESENTATIVE MEASUREMENTS OF HYDRAULIC PROPERTIES FOR FRACTURES DO NOT EXIST. THIS HAS NECESSITATED THE USE OF THEORETICAL PROPERTIES IN EQUATIONS WHICH PREDICT THE GROUNDWATER TRAVEL TIME. THESE THEORETICAL PROPERTIES AND RELATIONSHIPS, WHICH HAVE THEIR ORIGIN IN SOIL PHYSICS, HAVE NOT BEEN DEMONSTRATED TO BE REPRESENTATIVE OF A FRACTURED POROUS MEDIA LIKE YUCCA MOUNTAIN. FURTHERMORE, THE FEW FRACTURE FLOW MODEL CALCULATIONS APPLIED TO DATE BY DOE, SUCH AS THE INFILTRATION FLUX DISTRIBUTIONS USED IN THE WEEPS MODEL, HAVE BEEN OVERLY SIMPLISTIC. DESPITE GROWING FIELD EVIDENCE OF FLUX RATES ON THE ORDER OF 4-10 MM/YR IN SOME AREAS, THESE MODELS STILL UTILIZE (FOR THE MOST PART) FLUX RATES AN ORDER OF MAGNITUDE OR MORE LOWER. THEREFORE, THE UTILITY OF THESE MODELS FOR PREDICTING TRAVEL TIME WITH A REASONABLE LEVEL OF CONFIDENCE HAS YET TO BE DEMONSTRATED. DEPENDING ON ASSUMPTIONS USED, TRAVEL TIMES HAVE VARIED OVER FOUR ORDERS OF MAGNITUDE.

DIRECT MEASUREMENT OF GROUNDWATER FLOW IN FRACTURES AND AGE DATING OF FRACTURE WATER OFFERS THE BEST APPROACH FOR OBTAINING CONFIDENT

TRAVEL TIMES IN THE UNSATURATED ZONE. FLOW IN FRACTURES HAS BEEN WELL DOCUMENTED BY DOWNHOLE VIDEO CAMERA IN VARIOUS BOREHOLES ON YUCCA MOUNTAIN. DIRECT MEASUREMENT OF INFLOW RATES AND SAMPLING OF THOSE FLOWS FOR DATING HAVE BEEN SPARSE UNTIL RECENTLY. RESULTS FROM THESE SAMPLES HAVE BEEN SLOW IN COMING, BUT SOME RESULTS FROM DRILLHOLE UZ-16 WERE REPORTED TO THE NRC'S ADVISORY COMMITTEE ON NUCLEAR WASTE LAST DECEMBER. IN A HYDROLOGY WORKING GROUP SESSION, USGS AND LOS ALAMOS NATIONAL LABORATORY RESEARCHERS REPORTED POST-ATMOSPHERIC NUCLEAR WEAPONS TESTING AGES FOR CHLORINE-36 AND TRITIUM FOUND IN FRACTURE WATER ENCOUNTERED AT A DEPTH OF 1450 FEET. THAT DEPTH IS APPROXIMATELY 400 FEET BELOW THE PROPOSED REPOSITORY HORIZON AND STRONGLY INDICATES A FLOW PATH TO THAT DEPTH OF LESS THAN 50 YEARS. I ANTICIPATE THAT AS THE PROGRAM PLACES MORE EMPHASIS ON SAMPLES OF OPPORTUNITY WITH RESPECT TO UNSATURATED ZONE MOISTURE, ADDITIONAL EVIDENCE OF FAST PATHWAYS CONFIRMED BY AGE DATING WILL EMERGE.

LET ME NOW TURN TO THE SUBJECT OF GROUNDWATER TRAVEL TIME CALCULATION AND ITS PARTICULAR PROBLEMS AND THEN I WILL CONCLUDE WITH SOME COMMENTS ON DOE'S APPROACH TO THE GROUNDWATER TRAVEL TIME REQUIREMENT. ACCORDING TO NRC REGULATIONS AND DOE SITING GUIDELINES, THE CALCULATION OF GROUNDWATER TRAVEL TIME IS ALONG THE FASTEST PATH FROM THE EDGE OF THE DISTURBED ZONE TO THE ACCESSIBLE ENVIRONMENT. THE DISTURBED ZONE IS DEFINED AS: ..."THAT PORTION OF THE CONTROLLED AREA THE PHYSICAL OR CHEMICAL PROPERTIES OF WHICH HAVE CHANGED AS A RESULT OF UNDERGROUND FACILITY CONSTRUCTION OR AS

A RESULT OF HEAT GENERATED BY THE EMPLACED RADIOACTIVE WASTES SUCH THAT THE RESULTANT CHANGE OF PROPERTIES MAY HAVE A SIGNIFICANT EFFECT ON THE PERFORMANCE OF THE GEOLOGICAL REPOSITORY." SUBSEQUENTLY, THE NRC HAS CLARIFIED THE REASONING BEHIND THE DISTURBED ZONE BOUNDARY: "THE DISTURBED ZONE CRITERION IS INTENDED TO PREVENT THE RELIANCE ON ONLY THE ZONE DIRECTLY ADJACENT TO THE ENGINEERED FACILITY FOR THE MAJOR PORTION OF THE GEOLOGIC BARRIER PROTECTION, AND TO AVOID THE COMPLICATION OF CONSIDERATION OF COUPLED PROCESSES CLOSE TO THE EMPLACED HIGH-LEVEL WASTE WHEN DEMONSTRATING COMPLIANCE WITH THE GROUNDWATER TRAVEL TIME PERFORMANCE OBJECTIVE."

THE LAST QUOTE IS HIGHLY PERTINENT TO THE PROPOSED YUCCA MOUNTAIN REPOSITORY. THE MAJORITY OF TRAVEL TIME CREDIT FOR PRE-EMPLACEMENT CONDITIONS IS LIKELY TO OCCUR BETWEEN THE DISTURBED ZONE BENEATH THE REPOSITORY AND THE WATER TABLE. WITHIN THE SATURATED ZONE, TRAVEL TIMES ARE BELIEVED TO BE RELATIVELY FAST THROUGH THE FRACTURE NETWORKS TO THE ACCESSIBLE ENVIRONMENT. PUMPING TESTS OF THE SATURATED ZONE AT THE C-WELL COMPLEX HAVE CONFIRMED THIS BELIEF. THEREFORE, THE DETERMINATION OF THE DISTURBED ZONE BOUNDARY IS CRUCIAL TO THE CALCULATION OF GROUNDWATER TRAVEL TIME.

THE SUBJECT OF THE BOUNDARIES OF THE DISTURBED ZONE, WHERE THE CALCULATION OF GROUNDWATER TRAVEL TIME MUST BE INITIATED, HAS BEEN THE SOURCE OF MUCH CONFUSION AND DISCUSSION. DOE'S NEW PROPOSED

PROGRAM APPROACH (PPA), AS WE UNDERSTAND IT, ONLY ADDS TO THE CONFUSION. REFERRING TO MY EARLIER REMARKS, THE DISTURBED ZONE DEFINITION INCLUDES NOT ONLY REPOSITORY-INDUCED PHYSICAL AND CHEMICAL CHANGES BUT ALSO THERMAL CHANGES. AS THE BOARD HAS HEARD IN PAST MEETINGS, DOE PROPOSES A HIGH THERMAL LOADING STRATEGY FOR YUCCA MOUNTAIN. THAT STRATEGY HAS PROPOSED THERMAL LOADS WHICH COULD DRIVE THE TEMPERATURE RANGE UP TO AND ABOVE THE BOILING POINT AT THE WATER TABLE AND YIELD SIGNIFICANT TEMPERATURE INCREASES AT THE GROUND SURFACE. UNDER SUCH AN EXTREME THERMAL LOAD, THE LOCATION OF THE DISTURBED ZONE BOUNDARY WOULD LEAD TO THE CALCULATION OF AN EXTREMELY SHORT OR ZERO GROUND WATER TRAVEL TIME.

USING A HIGH THERMAL LOADING STRATEGY, THE SPECIFIC LOAD CONTROLS THE LOCATION OF THE DISTURBED ZONE BOUNDARY. HOWEVER, AS WE UNDERSTAND THE PPA, THE FINAL THERMAL LOAD FOR THE REPOSITORY WILL BE DEFINED ONLY AFTER THE SITE PERFORMANCE CONFIRMATION PERIOD, WHICH IS PLANNED TO BE 100 YEARS IN DURATION. IF THAT IS THE PROPOSAL, THEN A FINAL DISTURBED ZONE BOUNDARY CANNOT BE DEFINED AND THUS, A FINAL PRE-EMPLACEMENT GROUNDWATER TRAVEL TIME CANNOT BE ESTABLISHED FOR POSSIBLY 100 YEARS. THIS APPROACH CERTAINLY VIOLATES THE SPIRIT AND THE INTENT OF THE TRAVEL TIME CRITERION AS PROMULGATED BY BOTH THE NRC AND THE DOE.

A CONCERN RELATIVE TO CALCULATIONS OF GROUNDWATER TRAVEL TIME IN THE UNSATURATED ZONE IS THE USE OF AVERAGE VALUES. THE UNSATURATED ZONE IS A COMPLEX, DYNAMIC SYSTEM, WHERE AVERAGE HYDRAULIC

PARAMETER VALUES HAVE LITTLE MEANING RELATIVE TO ADDRESSING TRAVEL TIME ALONG THE FASTEST PATHWAY. OF SPECIAL CONCERN IS THE INFLUENCE OF SHORT-TERM, HIGH INTENSITY PRECIPITATION EVENTS THAT COULD LEAD TO VERY RAPID TRAVEL TIMES TO THE WATER TABLE. TYLER (1986) REPORTED OCCURRENCES OF DOWNWARD WATER VELOCITIES AS HIGH AS 60 METERS/YEAR IN FRACTURED TUFF ENVIRONMENTS IN THE VICINITY OF YUCCA MOUNTAIN. GIVEN THESE PAST OCCURRENCES, IT IS CLEAR THAT DOE MUST DETERMINE, CONCLUSIVELY, IF THE MAGNITUDE OF WATER MOVEMENT CONSISTENT WITH THESE RECORDED EVENTS IS OCCURRING AT THE REPOSITORY SITE. IT WILL NOT BE ADEQUATE FOR SITE CHARACTERIZATION TO ESTIMATE THE PROBABILITY OF SUCH FLOW OCCURRING, BUT RATHER SITE CHARACTERIZATION MUST DETERMINE IF IT ACTUALLY DOES OCCUR. IF THIS FLOW IS FOUND TO OCCUR BELOW THE REPOSITORY HORIZON, THEN CLEARLY IT REPRESENTS A FAST PATH AND OTHER, SLOWER PATHS SUCH AS MATRIX PATHWAYS SHOULD NOT ENTER OR BE AVERAGED INTO THE CALCULATION.

NOW I WILL TURN TO THE SUBJECT OF DOE'S APPROACH TO DETERMINING COMPLIANCE WITH THE GROUNDWATER TRAVEL TIME CRITERION. AS WE UNDERSTAND BOTH THE APRIL 1994 PRESENTATION TO THE BOARD AND THE JUNE 10, 1994 LETTER TO THE NRC ON THE SUBJECT, THE DEPARTMENT PROPOSES THAT THE PRE-WASTE EMPLACEMENT GROUNDWATER TRAVEL TIME BE CONSIDERED A DISTRIBUTION THAT DEFINES THE LIKELIHOOD OF EACH WATER PARTICLE REACHING THE ACCESSIBLE ENVIRONMENT AT A SPECIFIC TIME. THUS, GROUNDWATER TRAVEL TIME DISTRIBUTION IS A DISTRIBUTION OF WATER PARTICLE TRANSPORT TIMES. THE APPROACH INVOLVES DEVELOPING SEPARATE DISTRIBUTIONS FOR TRANSPORT FROM THE BOUNDARY OF THE

DISTURBED ZONE THROUGH THE UNSATURATED ZONE AND, IN THE SATURATED ZONE, FROM THE GROUNDWATER TABLE TO THE ACCESSIBLE ENVIRONMENT. THEN THE APPROACH WOULD SUM THE RESULTANT DISTRIBUTIONS AND EVALUATE THE SIGNIFICANCE OF THE TRAVEL TIMES ON SYSTEM PERFORMANCE.

THE STATE'S POSITION IS THAT THE DOE APPROACH VIOLATES BOTH THE INTENT AND THE LANGUAGE OF THE TRAVEL TIME CRITERION AND SHOULD BE REJECTED BY BOTH THIS BOARD AND THE NRC. AS I STATED EARLIER, THE NRC CRITERION WAS ESTABLISHED TO TEST THE NATURAL SYSTEMS ABILITY TO ISOLATE RADIOACTIVE WASTE, AND THE DOE, IN ITS OWN SITING GUIDELINES, ESTABLISHED A DISQUALIFYING CONDITION TO REJECT SITES WHICH COULD NOT, OR LIKELY COULD NOT, MEET THE WASTE ISOLATION NATURAL SYSTEM TEST. A KEY ELEMENT OF THAT TEST IS DEFINING THE FASTEST PATHWAY. DEFINITION OF THE FASTEST PATHWAY AND WHETHER A WATER PARTICLE TRAVELING ALONG THE FASTEST PATHWAY TAKES LONGER OR SHORTER THAN 1000 YEARS TO ACCOMPLISH THE TRIP LEADS TO A PASS OR FAIL GRADE RELATIVE TO THE CRITERION. FOR A PARTICULAR SITE, THERE CAN BE ONLY ONE FASTEST PATHWAY OF RADIONUCLIDE TRAVEL. THE DOE'S PPA APPROACH FAILS TO ADDRESS IDENTIFICATION OF THE FASTEST PATHWAY AND POSSIBLE METHODS THAT COULD HELP DEFINE THE PATHWAY.

DISTRIBUTION OF WATER PARTICLE TRANSPORT TIMES HAS A PLACE IN EVALUATING SITE PERFORMANCE THROUGH CUMULATIVE DISTRIBUTION FUNCTIONS. IT IS IMPORTANT TO ASSESS RADIONUCLIDE TRANSPORT PERFORMANCE BY EVALUATING THE EXTREMES OF THESE DISTRIBUTION

FUNCTIONS. THOSE DISTRIBUTION FUNCTIONS MAY OR MAY NOT INCLUDE THE PRE-WASTE EMPLACEMENT GROUNDWATER TRAVEL TIME FASTEST PATHWAY. THE DEPARTMENT HAS INTERPRETED THE GROUNDWATER TRAVEL TIME CRITERION AS A SUB-ELEMENT OF SITE SYSTEM PERFORMANCE. THAT IS CLEARLY A MISINTERPRETATION.

THE PROPOSED DOE APPROACH ACKNOWLEDGES THE NRC DEFINITION OF DISTURBED ZONE AND ITS APPLICATION TO ESTABLISHING A BOUNDARY FOR THE DISTURBED ZONE. THE APPROACH RECOGNIZES THAT THE DISTURBED ZONE INCLUDES PHYSICAL AND CHEMICAL PROPERTY CHANGES WHICH COULD SIGNIFICANTLY AFFECT REPOSITORY PERFORMANCE. HOWEVER, THE APPROACH FAILS TO ACKNOWLEDGE THAT THERMAL CHANGES AND THE RESULTANT CHANGES IN THE PHYSICAL AND CHEMICAL PROPERTIES MUST ALSO BE CONSIDERED IN DEFINING THE DISTURBED ZONE AROUND THE REPOSITORY . THE OMISSION OF THERMAL ASPECTS IS, IN OUR VIEW, CONTRIVED SINCE ITS INCLUSION WOULD HAVE THE AFFECT OF ENLARGING THE DISTURBED ZONE AND REDUCING THE GROUNDWATER TRAVEL TIME.

THE APPROACH ALSO FAILS TO RECOGNIZE THAT THE DEFINITION OF GROUND WATER FLOW MAY INCLUDE TWO PHASES OF WATER: LIQUID AND VAPOR. THE BOARD IS WELL AWARE OF NEVADA'S VIEW THAT THE DEFINITION OF GROUNDWATER INCLUDES BOTH PHASES, AND THEREFORE, THE GROUNDWATER TRAVEL TIME CRITERION MUST INCLUDE VAPOR-PHASE TRAVEL TIME. THIS IS THE BASIS OF NEVADA'S INSISTENCE ON THE TIMELY CHARACTERIZATION OF THE PNEUMATIC PATHWAYS AT YUCCA MOUNTAIN.

IN CONCLUSION, THE GROUNDWATER TRAVEL TIME CRITERION, AS PROMULGATED, IS A TEST OF THE ABILITY OF A SITE'S NATURAL SYSTEM TO ISOLATE RADIOACTIVE WASTE. IT PROVIDES AN OBJECTIVE, NUMERICAL STANDARD BY WHICH ALL PARTIES CAN JUDGE THE "GOODNESS" OF A SITE. THE DOE APPROACH INTRODUCES A SUBJECTIVE REINTERPRETATION WHICH PLACES PREMATURE IMPORTANCE ON MEETING PERFORMANCE OBJECTIVES BY RELYING ON ASSUMED PARAMETERS INSTEAD OF ATTEMPTING TO DIRECTLY ASSESS SITE SUITABILITY. I REQUEST THE BOARD EVALUATE DOE'S APPROACH VERY CAREFULLY BEFORE GIVING ANY ENDORSEMENTS.