EFFECTS EVALUATION POST-SHOT RE-ENTRY
PROJECT RULISON (U)

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I. INTRODUCTION

Post-event drillback at Project RULISON will result in the release of explosion-produced radioactivity. This release may take one or more of the following forms:

1. instantaneous release of all explosion-produced radioactivity at the surface (worst case);
2. a plausible accident consisting of rapid blow-out through the drill hole;
3. leakage during drillback (release of radioactivity less rapid than in situation (2);
4. release of radioactivity during gas flaring;
5. presence of radioactivity in drilling wastes.

For each case it is necessary to define the amount and nature of radionuclides released (primary source term); modification of the primary source term via meteorologic effects and/or redeposition (creation of secondary source term); and redistribution of radioactivity in the environment by surface and subsurface water.

Pre-drillback prediction of radiological effects and potential hazards will be developed from models utilizing existing data and/or reasonable approximations whenever data are lacking. Confirmatory sample collection, analysis, and data review are required for updating hazards and effects models. Also required, in the interest of public assurance, is the prompt release of data confirming the accuracy of predictive models and safe execution of drillback operations.
II. GENERAL CONSIDERATIONS

The original source term present in the explosion-produced cavity consists of products of nuclear fission and of neutron activation of device materials, emplacement materials, and the surrounding geologic media. The radioactive species constituting the original source term will be present to varying degrees in solid, liquid, and gaseous states within the cavity and rubble chimney. Definition of source terms at the surface arising from any of the five release mechanisms listed earlier requires determination of fractions of radioactive species present in the original source term which could be transported to the surface.

Meteorologic transport evaluations will utilize pre-shot climatological studies of winds and atmospheric stability in the RULISON area. Previously developed mathematical dispersion models\(^1,2\) will be modified to incorporate orographic effects and surface roughness peculiar to the Battlement Creek Valley area. In addition, data collected in the Battlement Creek Valley at four mechanical weather stations and from three "pibal" release stations will be reviewed and predictions of possible trajectories and dispersion of contaminants will be made.

Airborne radioactivity moving away from the RULISON site as a plume is subject to deposition. Some of the plume components will be particulates; e.g., fission product fragments as fine dust and combustion particulates in the form of soot. Particles settle out due to the influence of gravity and by precipitation washout. The rate of settling depends on the spectrum of particle sizes, the rate of growth of particles due to hydration or decomposition, atmospheric dispersion, and the washout effect.

The bulk of the airborne radionuclides, however, will be gaseous. The principal nuclides will be tritiated water as steam, and krypton-85. These by-products also will be subject to settling and substantial portions may be deposited on the ground surface. The methods of deposition for a
gas are not as predictable as for large particulates; gases can be carried to the ground dissolved in rain, snow, or even condensation water. This would be particularly true in the case of tritium which will behave like the bulk of meteoric water.

Once the released radioactivity comes in contact with the ground surface, it is subject to redistribution in the hydrologic cycle. The hydrologic cycle involves circulation of water back into the atmosphere, and the flow of water on and below the ground surface. As long as the radionuclides remain in solution, they will continue to be redistributed as a consequence of this circulatory system.

An inevitability of a drillback operation is that some material will be flushed to the surface, whether gas or water-mud drilling fluid is used. Waste drilling mud, presumably to be collected in holding ponds at the surface, could be contaminated with tritiated water and radionuclides adsorbed on particulate material or in aqueous solution. Recirculation, with scrubbers and settling pond, will result in bulky, liquid radionuclide-bearing waste residue. The waste may be transported off-site to disposal sites, intentionally evaporated from an impervious lined pond, or injected into a deep waste-storage well. The injection method requires knowledge of hydrologic conditions, especially of the proposed storage formation and of adjacent or nearby fresh water aquifers, to insure that transport of unacceptable levels of radioactive wastes from storage to a source of public supply does not occur.
III. SPECIFIC CASES

In consideration of cases other than instantaneous release (worst case) it is apparent that the most probable surficial primary source term would consist of gaseous and highly volatile species such as the inert gases (argon, krypton and xenon), hydrogen, carbon oxides, water vapor, and light hydrocarbons, to the extent that such gases are present 180 days after detonation. Although the inert gases would interact minimally, if at all, with the environment, account must be taken of the possibility that an extremely rapid release might temporarily create hazardous atmospheric concentrations. Hydrogen, water vapor, and hydrocarbons would contain tritium; combustion of tritiated hydrogen and hydrocarbons by flaring would produce tritiated water in excess of that exiting directly from the cavity. Carbon oxides (CO, CO₂) and hydrocarbons might also contain carbon-14 produced by neutron activation of materials in and around the nuclear device, primarily nitrogen. Nitrogen was present in the high-explosive detonator of the device, in a region of high neutron flux; also, it is known that underground gas bodies sometimes contain high concentrations of nitrogen gas. Carbon oxides containing carbon-14 would contribute to a gaseous source term, while incomplete combustion of carbon-14-labeled hydrocarbons during flaring might produce particulate, elemental carbon (soot) which could fall out within a localized area.

Sufficiently rapid efflux of gas through the reentry hole might entrain particulate material consisting of fragments of radioactive glass or, more likely, fragments of rubble with surficially adsorbed radioactivity. If liquid water is present in the cavity, the possibility exists for entrainment of an aqueous aerosol containing dissolved radioactive material. Both processes would create a primary source term different in composition and radiological properties from that produced by the gaseous phase alone. Extent of isolation and containment of a source term of this type would depend on the efficiency of trapping or filtering systems installed at the well-head.
The data necessary to predict the temporal and spatial distribution of radionuclides must include:

(a) Source term: For each type of accident the amount of gaseous and particulate radioactive material must be known. In addition, estimates must be made of the relative quantities of chemically and physically stable gases such as argon and krypton as opposed to the unstable ones such as iodine and water vapor. Similarly, it is necessary to estimate the particle size spectra and the distribution of radioactivity as a function of particle size for each case of release.

The duration and rate of leakage will be different for each type of hypothetical accident. This information, combined with the knowledge of the amount of total material available, must be used to calculate the initial source term for the atmospheric dispersion calculations, and will result in different secondary source terms for each case.

(b) Atmospheric dispersion: Data on the frequency distribution and ranges of wind speed and direction must be used as guidelines in calculating the highest dosages that could be received from any given accident. Special attention must be paid to local orographic effects which could enhance or retard atmospheric dispersion of radioactive material or channel it to some previously unsuspected area. The nature and duration of various conditions of atmospheric stability must be considered, since they drastically affect dispersion rates.

Meteorologic transport effects must be evaluated to determine arrival times of the radioactive plume and the concentration of each radionuclide as a function of time for various distances downwind from the release point. This information must be obtained for each type of accident, for stable, neutral, and unstable meteorological conditions, and as a function
of wind speed. Concentration as a function of time at a given point can be expressed as a dosage that would be received by personnel in that area. In determining the atmospheric concentrations and personnel dosages, it is necessary to consider reduction of the source terms by radioactive decay, atmospheric dispersion, adsorption of gases, and precipitation of particulates. As radioactive particulates may be present in all of the hypothetical accidents, it is necessary to estimate the particle-size spectrum for the entrained, non-volatile radionuclides and the distribution of activity with particle size.

Tables and graphical plots should be provided for hot-line concentrations, time of arrival and duration of the plume, and resultant dosages for stable, neutral, and unstable meteorological conditions. These data should be provided as a function of wind speed for each type of accidental release.

The secondary source term, deposited in watersheds, will consist of particulate material and radionuclides dissolved in water. Particulate material which is not subject to solution in water probably will remain in place; however, some transport resulting from erosion and subsequent overland flow as sediment could take place. The biggest potential for radionuclide movement, however, is by the leaching of the surface-deposited material by rainwater.

When fallout occurs on a substantial snow cover of the watershed, experience has shown that material deposited on the snow remains in place until the snow cover melts and allows the fallout to contact the ground.\textsuperscript{3,4}

Fallout radioactivity which goes into solution will move the water as stream runoff or will percolate into the ground-water reservoir. In many cases there will be some residence time for radioactivity in water in both the surface-water and ground-water systems.
Gaseous radionuclides will likely combine with atmospheric moisture, and then be deposited on the land surface. A fraction will return to the atmosphere by evaporation with the remainder subject to overland flow as runoff or into the ground-water reservoir by infiltration. As in the case of particulate fallout, radioactivity of gaseous origin may become part of the snow or ice pack and, consequently, be unable to move at least until a thaw takes place.

Many factors affect the manner in which a radionuclide deposited on the land surface may be free to move. Three major areas of data requirement describe the whole transport problem: chemical interaction of earth materials and nuclides in solution and suspension; hydrogeology of the watershed; and local/regional meteorology. Specific requirements include retardation characteristics of the earth materials in the watershed, size and shape of the watershed and its reservoir, radionuclide deposition pattern and history, and the meteorological/climatological history and stream hydrograph(s) for the particular watershed under investigation.

The general problem of radionuclide transport within a watershed has been analyzed in some detail for situations similar to the RULISON event. A comprehensive study was made for redistribution of fallout of radionuclides for the specific conditions that could be expected around the nuclear-excavated, sea-level canals in Panama and Columbia. For these studies, a computer model was developed which calculated nuclide balances and allowed a prediction of the radionuclide inventory on the land surface, in run-off water, and in the ground water.

To perform a redistribution analysis at RULISON, we propose to use the experience and the redistribution models already developed to predict radiological effects and possible hazards. Output resulting from the redistribution analysis will be prediction of the temporal and spatial distribution of RULISON-related radioactivity wherever it is detectable above natural background levels as well as wherever levels may represent
potential hazards. Predictions will be for the combined ground-water and surface-water watershed model.

In the case of disposal of drillback wastes, the principles and feasibility of deep-well storage may be applied readily to the RULISON site. The facts which must be known for successful deep-well injection are:

(1) Dimensions, rock contacts, geologic structure, lithology, host-rock porosity, permeability, and chemical properties of the injection horizon.

(2) Chemical properties of fluid in the injection horizon and of the fluid being injected.

(3) Hydraulic properties of the injection horizon, i.e., direction, velocity of flow, hydraulic potential.

(4) Lithology, structure, and dimensions of confining, less permeable formations. Both overlying and underlying formations must be considered. An impermeable overlying formation alone does not assure safe storage.

(5) Formation pressure and hydrostatic head at injection depth, to assure that the volume of waste to be injected can be injected at pressure which will not cause unacceptable hydrofracturing.

Given these data, or by making reasonable but credible estimates, transport by ground water can be predicted. As in the case of the watershed model, predictions will clearly define spatial limits of potential hazardous levels of the detectable above background levels of radioactivity.
IV. WORK STATEMENT

The following items will be evaluated in order to define primary source terms for events postulated to occur during the drillback operation and during gas flaring:

(1) Chemical and radiochemical gas analytical data generated during the GASBUGGY experiment will be collected and reviewed. Existing data on gas quality, composition of geologic media, and other properties of the media near the RULISON working point will be collected as input for computational definition of primary source terms.

(2) Kinds and quantities of radionuclides, produced by the nuclear detonation and existing six months later, will be identified.

(3) To the extent possible, the physical and chemical states and spatial distributions of significant radionuclides in the cavity and rubble chimney will be defined.

(4) For any given means of release to the surface, a source term produced at the surface will be defined, based on information developed in the preceding items and on the postulated mechanism of release. Account will be taken of any changes in chemical and physical states of radionuclides caused by the mechanism of release (e.g., partial or complete combustion of gases during flaring).

These work items will be accomplished by application of theoretical models and computational methods developed at Isotopes in the Long Range Program of the Ground Water Study. Data from the GASBUGGY experiment will be applied when applicable, and are expected to be of considerable assistance. The results will be used as necessary input to transport models appropriate to various postulated mechanisms of release.
For the determination of the secondary source terms it will be necessary to perform the following tasks:

(1) Collect and review applicable meteorological and orographic data. Data of particular relevance will include frequency distributions of wind speed and direction (wind roses) and atmospheric stability.

(2) Select and program meteorological dispersion models. Previously developed numerical models for the dispersion and deposition of gaseous and particulate radionuclides will be modified with particular attention given to modifying pertinent local conditions.

(3) Computation and analysis of results. Concentrations and dosages will be computed for each source term over the range of possible meteorological conditions. Areas which may become potentially hazardous will be delineated so that they may receive special attention.

(4) Report writing. The results of the calculations will be presented in tabular form as well as in the form of maps depicting isopleths.

The two main areas that will be delineated for each type of accident and set of meteorological conditions so as to receive special emphasis will be: (a) that area in which the level of radioactivity is above the normal (pre-shot) background; and (b) that area in which the level of radioactivity may be considered hazardous.

To perform the analysis of redistribution for radionuclides deposited on watersheds at the RULISON Site, we propose the following:

(1) Assemble all available hydrologic and geologic data. This will include all relevant data on vegetation cover, topography, soil types, porosity, hydraulic conductivity, stream hydrographs
with base flow estimates, and ground-water reservoir size for each of the watersheds that might be affected by drillback at RULISON. Where no data exist, reasonable credible estimates will be made.

(2) Assemble meteorologic and climatologic data. This will include all relevant data on evaporation, time history of precipitation, and long and short term infiltration rates. Where data are not available, best estimates will be made.

(3) Evaluate the deposition area. This will include determining the source of water for all known use points, assigning data from (1) and (2) above to each controlling watershed, and determining the potential pathways of radionuclide movement at the RULISON Site.

(4) Calculate redistribution rates. For each radionuclide of interest, calculations of redistribution will be made that demonstrate the effects of changes in rainfall rates, changes in deposition rates, and changes in rainfall and deposition patterns.

(5) Evaluate the redistribution effect. Following these preliminary estimates, those areas where radionuclides apparently would concentrate or not be diluted will be identified. If additional data need be collected to refine calculation in these areas, a sampling program will be defined.

A complete report of results of the studies outlined above will be written.

Isotopes proposes to perform an initial study of the area within reasonable economic pipeline distances of the RULISON drillback hole (<5 miles) to determine feasibility of deep well storage of radioactive waste associated with drilling. The initial study would involve examination
of available literature and all disposal well test data to indicate areal position(s) of disposal well site(s) and target depths of any acceptable horizons. Hydraulic properties of stratigraphy of the disposal site area, potential alteration of host rock by injection, and possible effects on regional and local water supply will be evaluated. Graphs of formation-pressure increase and pressure-radius extension versus injection time will be constructed using available or credible, assumed values for:

1. formation pressure,
2. permeability,
3. thickness,
4. porosity,
5. injection fluid viscosity,
6. injection rate,
7. fluid compressibility.

Available chemical data are probably sufficient to predict whether acidizing and buffered water are necessary to prevent formation of gelatinous precipitants during injection.

Specific recommendations for a field program necessary to supply required additional data for selection of disposal sites will be provided. An explicit program for drilling, testing, and completion of wells will also be provided.

The initial phase of work will include a complete report evaluating feasibility of the deep waste-injection well. Only positive indications that neither unacceptable contamination nor stimulation of ground motion would occur must precede any direct commitment to further field exploration and disposal-associated engineering and construction phases. The proposed study will indicate whether deep-well injection and storage is an available choice for RULISON drillback and chimney-flush wastes.
REFERENCES


