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OPPORTUNITIES AND RESPONSIBILITIES OF EARTH SCIENTISTS IN THE NUCLEAR AGE

Prepared by the U. S. Geological Survey on behalf of the U. S. Atomic Energy Commission

UNITED STATES DEPARTMENT OF THE INTERIOR
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By E. B. Eckel

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ABSTRACT

Underground testing of weapons or other nuclear devices has already required many man-years of effort in geologic, geophysical, and hydrologic fields. Any future underground tests will require similar efforts in providing advice on sites, feasibility, and interpretation of the explosions. Similarly, all offensive or defensive installations of any kind require geologic facts in site selection and in design and construction. Many peaceful applications of nuclear explosions have been proposed; others are sure to be proposed in the future. Each such proposal will require evaluation, in part by earth scientists, and some will go as far as full-scale tests or even to commercial applications. Much additional information on the effects of explosions in various kinds of rock is needed before it will be safe to extrapolate from the previous tests in a single rock type in Nevada. The success of the nuclear-reactor program depends in part on geologic and hydrologic knowledge in helping to solve site selection, construction, and water-supply problems. More important, however, are studies of the disposal of radioactive wastes from reactors and similar plants. Parallel with the duties of geologists in the nuclear age are many opportunities to learn more about seismology, structural geology, mineralogy, volcanology, and other branches of earth science—all in large-scale controlled experiments. The paper includes a partial bibliography of the rapidly growing amount of literature on the subject.

RESPONSIBILITIES

This paper is confined to a very small fraction of the total geologic problems of the nuclear age—that is, to those more or less directly related to the release of nuclear energy. Even within this restricted field our job is large.

Military Applications

Energy releases by weapons or by explosive devices applied to peaceful purposes—so-called uncontrolled releases—pose many problems. The geologist must supply all the geologic facts that have any bearing on the safety, efficiency, or economy of such explosions.

Even though it poses many special problems, both technical and political, underground testing of nuclear weapons or other devices has many advantages over surface or above-surface testing. Since 1956, when the Atomic Energy Commission began serious plans for underground tests, the U.S. Geological Survey has been rather deeply involved in this aspect of nuclear-energy releases. Its job has been to advise the Commission on three essential points—selection of sites for contained underground tests, prediction of seismic effects both on and off the test site, and assessment of ground-water contamination problems. To carry out these responsibilities the Survey has performed many man-years of effort—geologic, geophysical, and hydrologic. In doing so it has had a rare opportunity to correlate surface and underground geologic mapping and other field studies with the results of extensive chemical, petrographic, and physical-properties measurements made in the laboratory. All of these interrelated facts have been used by the Survey and by many other groups in advising on the feasibility and interpretation of underground blasts of conventional and nuclear explosives.

Aside from the testing of nuclear weapons, the very fact that the world has nuclear weapons opens up an enormously broad field for the engineering geologist. We must, apparently, be prepared to use nuclear weapons and to defend ourselves against them. This means that we must consider building everthing from at least backyard bomb shelters to vast underground factories and nerve centers to "hard" sites for nuclear-missile launchers. These last installations must be ready to fire at all times. Yet they must be invulnerable to near hits by enemy missiles and to the radioactive material these may produce.

Sites for offense or defense, or both, offer far bigger problems than geologic ones. But geologists and soils engineers have a very real duty and responsibility to assist in site selections and in the design and construction stages of all offensive or defensive installations.

Peaceful Applications

Peaceful applications of nuclear explosions that have been proposed range widely in their scope and in the degree of economic or technologic soundness. Few if any of the proposals are new to the world—they merely propose to apply new methods to things that man has done or dreamed of in the past.

Several thousand years ago, it was said that faith can remove mountains. More recently, Stalin spoke of moving mountains; almost certainly he was thinking of applying nuclear energy, rather than faith, to the task.

The French recently revived a 90-year-old proposal to change the climate of North Africa—this time by using nuclear explosives to open a passage from the Mediterranean to those parts of the Sahara that are below sea level.

Some of the proposals that have been made in this country are these:

1. Increase of fractures, hence an increase of stream production, in geothermal areas.

2. Application of the heat-pump principle to withdraw energy from a deeply buried mass of rock heated by a nuclear explosion.

3. Development of harbors and channels in Alaska and elsewhere.

4. Excavation of a sea-level trans-Isthmian canal.

5. Development of oil-shale resources, either by breaking large amounts of shale to make it ready for cheap mining or by underground distillation of shale oil.

6. Liquefaction of tar in tar sands by heat from a nuclear explosion.

7. Minute fracturing of large low-grade metallic-ore deposits, preparatory to in-place leaching.

8. Increased production of water by fracturing of proper strata.

9. Artificial ground-water recharge by fracture of impermeable beds between source and potential aquifer.

10. Storage of oil and gas in rocks fractured by nuclear explosions.

11. Construction of headwater detention dams by blasting of canyon walls.

12. Production of valuable isotopes by breeder reactions deep within the earth.

13. Production of diamonds and other gem minerals.

Some of these proposals appear to be more fantastic than others and some will certainly be dropped from consideration after preliminary study. But others are equally certain to be tried, and some of these will prove successful. Moreover, we have just begun to think in terms of peaceful uses for nuclear explosions. For each scheme that has already been suggested there are certain to be several new ones proposed in the months and years to come. Each one of these will require evaluation, in part by earth scientists, and some will go as far as full-scale tests or even to real commercial applications.

Virtually all of the proposed peaceful uses for nuclear explosives depend on the heat generated by the explosion or on the ability of the explosion to break or excavate large quantities of rock. Any specific scheme will of course require intensive studies of many kinds, ranging from economics to determination of the physical and hydrologic properties of the rocks that will be affected.

On the basis of the present state of our economics and technology, it is easy for a geologist to see that nuclear explosives can be used only for very large projects. But if the project is large enough, the use of nuclear explosives may indeed prove economical. It is possible that the price of a nominal 20-kiloton device, emplaced and fired, would be no more than $500,000. Now, 20,000 tons of dynamite would cost about 20 times as much as this, delivered at the site. Moreover, whereas a 20-kiloton nuclear device could be emplaced in a fair-sized drill hole, or in a room of only a few cubic feet, the equivalent amount of dynamite would require more than 20,000 cubic yards of space. The cost of excavation and support of a room of this size would be a very considerable addition to the cost of the explosive itself. And the resultant dynamite explosion would not be a point source of energy in either time or space! The economic contrasts become even more pronounced with larger explosions. A megaton device—1 million tons of TNT equivalent—can be bought for 1 million dollars!

There is, of course, a fallacy involved in direct comparisons between nuclear and conventional explosives. The rates of propagation of energy are of entirely different orders of magnitude, and the partitions of energy between shock, heat, and radiation are very different. Still, the orthodox comparison between total energy yields of TNT and nuclear explosions is the most convenient handle we have to use.

It is obvious that we will not be ready for any large-scale peaceful applications of nuclear explosives until we know much more about a number of different kinds of rocks and geologic settings. As a result of half a dozen tests, all more or less contained, we know a great deal about the effects of explosions on the rhyolitic tuff of the Oak Spring formation in Nevada. This tuff was chosen for the early tests because it is thick, relatively uniform, easily tunneled, and weathers to steep slopes. It was also chosen because the porosity, water content, and mineralogic composition of the tuff permit it to absorb shock waves and radioactive contaminants, yet to dissipate heat rather rapidly. Hence it provided almost ideal conditions for the tests. But rocks like the Oak Spring are comparatively rare. Before we can have much confidence in extrapolating from the recent tests in Nevada we need to know much more about the results of tests in many other media—rocks of different hardness, toughness, and chemical composition. We also need to know much more about the effects of joints and other structural features that are common to all rocks but in greatly varying degree.

Power Production

"Controlled" releases of energy, here limited to production of nuclear power, offer similar responsibilities. Schemes for increasing the heat release from geothermal regions by nuclear explosives, as well as schemes for underground storage of heat from explosions, are not strictly classed as controlled energy releases. Yet the ultimate extraction of the heat produced will be very closely controlled. Controlled or not, all such schemes are primarily geologic problems.

All reactors, whether for production of power or for breeding of isotopes, require large amounts of surface or ground water. Many reactors will be built partly or wholly within the ground. Site selection, construction, and water supply all require geologic advice.

The safe, long-term disposal of radioactive fission-product wastes, however, is one of the important problems ahead of us in the controlled release of energy. If the problem is not solved it could prove to be a limiting factor in our development of atomic power as an energy source. Great quantities of wastes must be either drowned in the ocean, buried in the ground, or safely dispersed in natural environments. Wherever we put them the longer lived nuclides must stay safely where they are for centuries and must not contaminate ground-water supplies or mineral deposits that may be needed in the future. It is also desirable that they be recoverable at will, for there is always the possibility that new uses will be found for various fission products.

Waste disposal thus offers great challenges and opportunities to earth scientists. The individual job may be a simple one of site selection for a concrete burial vault, or determination that a given mine, cave, salt dome, or depleted natural-gas reservoir will or will not be a good container for liquid or solid wastes. But it may just as well be the discovery and delineation of a structural basin thousands of feet deep, with no potentially useful mineral or fuel deposits within it, with permeable beds in its lower portions, and with no possible connection between those beds and water- or oil-bearing horizons closer to the surface.

OPPORTUNITIES FOR THE EARTH SCIENTIST

This cataloging of responsibilities implies a large number of opportunities for the earth scientist. Some of these implications have to do with jobs or with the ability to add to our knowledge of the country by means of the detailed geologic maps, backed up by thorough exploration, that we will have to produce. There are, however, other opportunities for fundamental research in the earth sciences.

The seismologist can use nuclear blasts to measure shock waves whose origins, in terms of time, place, and energy, are known in very exact terms. Further, he can use these measurements in studying the makeup of the earth.

The structural geologist can study the deformations in different kinds of rocks caused by point sources of energy. The volcanologist can study the effects on rocks of extremely high temperatures applied for transient periods. The mineralogist must learn how—and if—clay and other minerals adsorb radioactive isotopes and how mineral properties are changed by intense radiation, heat, and pressure. The economic geologist will be able to aid in efforts to produce economic deposits of radioisotopes or to develop submarginal ore deposits; he will be able to make and freeze magmas whose composition he knows or can even control. The engineering geologist will perforce accumulate extremely detailed information on small parts of the earth's crust; he will be able to correlate and interpret innumerable measurements of chemical, physical, petrologic, and structural properties of rock types and stratigraphic units in a way that has never been possible heretofore.

There are many actual and potential uses of nuclear reactions as tools for the geologists' trade. Gamma-ray and neutron logging of boreholes is already well known, as is age determination of rocks, soils, and water by means of radioisotopes. The years ahead will see growth in such methods as these, but perhaps even greater growth in other field and laboratory applications. For some elements, neutron-activation measurements, for example, are more sensitive than standard chemical analyses. Again, radioactive tracers can and will be used to study not only ground-water movements, but such things as cliff erosion and transportation of sediments. Soil moisture and density can now be measured in place by means of neutrons and gamma rays. Many other methods and gadgets will be developed for measurements of geologic processes and properties as time goes on—all to the benefit of the science.

Many of the things that the engineering geologist will be called on to do with regard to nuclear-energy releases are those that he is already expected to know. But if he is really to live up to his opportunities, he should broaden his fundamental knowledge. He should become aware, first of all, of the vast political and sociological implications of the forces with which he is working. Next, he should understand something of the meaning and mechanics of nuclear reactions, both fission and fusion. And the more he knows about such fields as radiochemistry, explosives engineering, and rock mechanics, the better will he do his job. We need, in fact, to develop a whole new concept of rock mechanics. We know a good deal about the effects of static loads on rocks. Now we need to learn as much or more about the effects of dynamic loads caused by instantaneous shock.

AVAILABLE LITERATURE

The literature of atomic energy is already enormous and is growing at least as fast as any other branch of knowledge. Many reports that deal with geologic aspects of atomic-energy releases are classified and are not available to the public. A surprisingly great and increasing number of reports, however, is unclassified and available to anyone who knows where to look for them. Some such reports are in the standard technical and scientific journals or in government publications. Many others are released by various contractors to the Atomic Energy Commission and are either for sale or for study in open files.

The appended partial bibliography of unclassified literature on geology in the nuclear age (exclusive of radioactive raw materials) amounts to little more than a sampling, but it will give the reader some idea as to the wealth of material that is already available. Many of the reports listed contain additional bibliographic references. Some of the material so listed is marked "for official use" or has other restrictions, even though this fact is not always indicated in the bibliographies. Because many restricted documents are subsequently released to open files or otherwise published, the earnest student would be well advised to inquire of the source agency as to the current status of such reports.

The expression $——— OTS means that the report is for sale by the Office of Technical Services, U.S. Department of Commerce, Washington 25, D. C. The expression (mf) means microfilm; photostat copies are also available, at somewhat higher cost, for most items listed as microfilm.

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Library, Room 1033, General Services Administration Building, Washington, D. C.

Library, Building 25, Federal Center, Denver, Colo.

Library, 345 Middlefield Road, Menlo Park, Calif.

504 Federal Building, Salt Lake City, Utah.

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