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RADIOLOGICAL SAFETY RESEARCH FOR NUCLEAR EXCAVATION PROJECTS - INTEROCEANIC CANAL STUDIES

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ABSTRACT

The general radiological problems encountered in nuclear cratering and nuclear excavation projects are discussed. Procedures for assessing radiological problems in such projects are outlined. Included in the discussions are source term, meteorology, fallout prediction and ecological factors. Continuing research requirements as well as pre- and post-excavation studies are important considerations. The procedures followed in the current interoceanic canal feasibility studies provide examples of radiological safety problems, current solutions and needed research.

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Many of the papers presented at this symposium have discussed research directed toward development of radiation protection guidance for Plowshare projects or the application of such guidance. There are several areas in which radiological safety problems can be attacked in this regard. These will be discussed here in terms of current approaches and some of the requirements for their improvement. The context in which they are presented here may be broader than some workers in the field would consider. Much of this discussion will reflect experience in the current interoceanic sea level canal feasibility studies conducted under the auspices of the Atlantic-Pacific Interoceanic Canal Study Commission. In these studies, a great deal of research has been conducted and additional needs have become apparent. A brief description of the interoceanic canal studies will be given here, especially of the nuclear safety aspects. For more detailed information on the overall program, reference is made to other publications (1-5).

The objectives of the interoceanic canal studies are to investigate the various aspects of construction of a sea level canal in the

American isthmian region. Primary consideration is given to excavation along routes in the vicinity of the Panama Canal by conventional means (Routes 10 and 14) and along routes in eastern Panama (Route 17) and northwestern Colombia (Route 25) by nuclear means, or a combination of nuclear and conventional means (Figure 1). Under consideration for nuclear excavation is a canal cross section providing a navigation prism 1,000 feet wide and 60 feet deep. Route 8, along the Nicaragua and Costa Rica border, involves a conceptual study only and will not be discussed here. Initial possibilities that were considered for nuclear excavation along Routes 17 and 25 included the elements in Table 1. While studies of the plans for excavation have not been concluded and will undoubtedly be different from these, this table indicates the extent of the program under consideration.

In connection with these studies several comprehensive programs were established and are continuing. The Atomic Energy Commission's role in these studies included nuclear safety programs in (1) airblast, (2) ground shock, (3) radioactivity, and (4) nuclear operations. Of these, the radioactivity studies are by far the most extensive. Other studies conducted by the Army Corps of Engineers, which to some extent provide information of importance to nuclear safety activities, include (1) topography, (2) geology, (3) hydrology, (4) medico-ecology, (5) nuclear excavation design, and (6) conventional engineering. While the discussion here is directed toward radiological problems, these should be kept in context with the overall purpose and other problems of equal or greater significance.

An assessment of a radiological situation in connection with a nuclear excavation project involves a number of factors. First, a description of the kinds, nature and amounts of radioactivity produced in proposed nuclear detonations is required. Also, the time sequence of radionuclide production is important. Together these may be designated the "source term." The nuclear devices contemplated for future excavation projects are relatively low in fission nuclide production. Much of the radioactivity produced will be through neutron activation of surrounding materials. While many of the radionuclides so produced are short-lived, they must be considered from the standpoint of total amounts produced. Therefore, the ability to estimate production of these nuclides becomes important. Through tests in the Plowshare program reliable estimates can be made of neutron-activated material associated with the device, as well as the fission products. This constitutes one area requiring study along with device design experiments.

Radionuclides produced through neutron activation of environmental material surrounding the device are, of course, dependent on the elemental constituents of the material which varies with geographical locations. Estimates of production of these radionuclides must be based on assumed constitution of the media in which devices will be emplaced. Where samples of such media can be obtained and chemical analyses made, the assumptions involved are improved. For feasibility studies of large-scale nuclear excavation projects, such as the proposed sea level canal, it is not practical to examine material at such emplacement site. However, data obtained from a variety of formations and geographical locations provide a basis for estimating a range of values for activation products. In general, it would seem that these estimates would be adequate for planning purposes. Additional experience through testing in different media may improve our ability in this regard.

The next area of concern is the distribution of radioactivity in the detonation process. Because of its immediate importance, atmospheric transport and deposition is considered first. The elements required for estimation of atmospheric transport and deposition include estimates of the radioactivity released to the atmosphere. This varies over a wide range for a given nuclear yield and depth of burial; again, it is dependent on the detonation environment. Also again, the better the environment is known, the better assumptions can be made in this regard, and our ability to predict these factors will improve through testing in different media. Based on some actual geological data estimates of these factors were made in the canal studies. A similar situation exists with regard to the dimensions of nuclear clouds, another important element in predicting fallout.

Through theoretical considerations and a great deal of experience in atmospheric weapons tests, close-in or local fallout prediction models have been developed which have proven reliable within the uncertainties of the elements mentioned above. These, of course, require knowledge of meteorological conditions. Here, it is important to have reliable data, more than climatological. For preliminary or feasibility studies, it is necessary to ascertain the frequency of favorable conditions, i.e. conditions under which fallout is confined to acceptable radiation levels within a designated sector or zone. Where such information is poorly known (and orographic situations require assessment), field programs are required to obtain it as is the case in the canal studies. With these data and assumptions, estimates can be made of locally deposited radioactivity. However, areas of weakness in our ability to assess this factor are (1) washout and rainout effects, (2) transport and deposition of tritiated water, and (3) transport and deposition beyond the local fallout zone. These, especially the first two, are not at all well-known and constitute items needing further research.

The remainder of the technical problems with assessing radiological situations deal with biological transport and its consequent effects on man. The external gamma radiation situation can be assessed from the treatment of deposition mentioned above. Situations so assessed which indicate an unacceptable situation obviously preclude the need for assessment of possible internal human radiation exposure. However, the latter contributes to total exposure and in certain cases can be critical. It is by far the most difficult assessment to make because of its complexity and its dependence on specific environmental information. The process involves tracing radionuclides through food webs to man. Here, it is necessary to consider also the radioactivity which was not released to the atmosphere. For example, ground water contamination needs consideration. Information required includes data on human populations and habits, particularly dietary data. The nature of the population and its habits will determine the ecological data needed. These, of course, vary widely with geographical regions as does the extent of available knowledge concerning them. As in the canal study situation, field studies to some degree at least are required.

Mathematical models, ranging from very simple to highly complex, have been developed to estimate internal radiation exposures to human populations. In general, the very simple models are highly empirical and leave much to be desired in assessing complex situations. On the other hand, the highly sophisticated models require data which are not available and are highly theoretical, perhaps only mathematically. Compromises have been suggested which appear to be practical, even though some assumptions must be made. In general, reasonable and practical field studies supplemented by existing information can provide the basic animal and plant population data required. A great deal is known with regard to many food webs and transport of a number of radionuclides through them. For some food webs and some radionuclides, it is necessary to make assumptions, and in a number of cases with few current bases. It is in these areas where continued and additional research is required. The behavior of some elements in man should be among these research goals.

The effects of radiocontamination of plants and animals other than man, as it may indirectly affect man, should be considered. In some cases, because of other activities (rapid urbanization or development) radiation effects could easily be dismissed. In any case, some assessment is possible at present.

The last element to be discussed here is radiation protection guidance. To some extent all of the above should be considered in discussions of radiation protection guidance. The application of our knowledge of radiation effects, and the lack of it, to the establishment of guides are obvious and have been discussed by others here. Considerable research is being conducted in this area, and as methods and techniques improve, the bases for radiation guides will become more sophisticated. As mentioned above, some advances can be made through research into the behavior of certain radionuclides in man. The major problems in the area of radiation protection guidance seems to be in the application and interpretation of guidance. Arguments of these problems often go far beyond our technical knowledge. The balance of risk and benefit concept is a difficult one to apply. The scales used for the balancing are seldom adjusted properly. This is an area where the researcher as well as the applied scientist and engineer can contribute to solutions of problems. If the problem is approached and reported in a scientific manner, at least the balancing process can be made easier in many respects.

The current interoceanic sea level canal feasibility study offers a good example of problems in radiological safety, along with other safety problems. The proposed project is the largest and most complex of any to date which could involve nuclear excavation. Also, it has involved the most detailed study of radiological safety of any proposed project to date. The approach being used in the studies involving nuclear excavation will be described briefly below.

The studies were begun assuming nuclear excavation designs for Routes 17 and 25 developed in the 1964 study which are summarized in Table 1. The final plans, yet to be arrived at, will depend on geological investigations, current cratering technology and safety considerations. Based on these preliminary designs and future nuclear devices contemplated for the projects, estimates were made of the radionuclides that would be produced in each detonation (6, 7). As mentioned above, the chemical composition of media of detonation points were assumed initially. Based on nuclear cratering experience to date and assumed geology, the percent of radioactivity entering the atmosphere and cloud heights were estimated for each detonation (4). These provided preliminary source term information.

Also, the radionuclides produced were analyzed as to their possible importance with regard to internal radiation dose to man. This involves a process of elimination from a list of several hundred radionuclides. A number of these can be eliminated on the basis of their very short half-lives or the very small quantities produced. The remainder are analyzed (8-10) from the standpoint of their contribution to potential total internal radiation exposure, either to critical organs or whole body exposure. For this purpose, data for and methods of estimating exposure recommended by the International Commission on Radiological Protection (ICRP) were employed. In addition, analyses were made employing the specific activity concept in a very conservative manner (7, 9, 11). For example, one can arrive at "Maximum Permissible Specific Activities" (MPSA's) based on ICRP values of Maximum Permissible Concentrations (MPC's) and stable element concentrations in "Standard Man." From these a list can be made of the relative importance of each radionuclide, then assuming the MPSA's to be reached, those contributing to about 99% of the internal dose can be determined. The remainder would be of little significance. Other similarly conservative estimates can be made, thus confirming the adequacy of this approach. The purpose of this analysis is not to ignore some radionuclides but to determine which require more intense study and especially to determine which stable element analyses should be made in field samples.

Two weather stations were established on each route being considered for nuclear excavation. From these stations meteorological data were obtained for fallout prediction purposes (4). Operations were for about 18 months on Route 17 and will be for about 24 months at one station on Route 25 (June 1969). Using wind data obtained over about a year, preliminary estimates of fallout indicated an area which may require evacuation of the indigenous population. Subsequently, an analysis was made to determine the days on which specific detonations could be conducted and the fallout confined to this exclusion zone. A similar process was carried out to determine days on which there would be no long range airblast damage. This provided an overall calendar of acceptable days for all proposed detonations. With these a schedule for each detonation was made for planning purposes. Using this schedule, all available meteorological data available, and a rapid computer model developed for this purpose, specific fallout predictions were made for Route 17 excavation. The latter are currently in process for Route 25.

These predictions are in the form of external gamma lifetime isodose contours for each detonation and a total for all detonations. From basic source term data, these can be converted to quantities of each radionuclide deposited. These provide a preliminary basis on which to assess the radiological implications involved in nuclear excavation. The total lifetime external gamma 0.1 R isodose contour for Route 17 was well within the initially selected exclusion zone. However, because of the uncertainties involved in the estimates and the possibility of unusual changes in wind patterns, it was not felt that the exclusion area should be reduced in area.

Concurrent with the meteorological field studies were other studies. Among these were ecological investigations (8). These consisted of literature, field and laboratory studies in human, terrestrial, freshwater, marine, and agricultural ecology, as well as hydrologic modeling studies. These provided a reasonably detailed description of the areas in the various fields although, except for seasonal variations, few studies of dynamics were made. Human populations were described with regard to location and dietary customs, as well as other demographic variables such as population-area trends of the various groups. About five distinct population groups are involved.

Food webs leading to man were identified and elemental chemical analyses of environmental samples provide information on the biological availability and concentration of stable elements in the various systems. With these data, ecological transport models can be realistically modified to represent more nearly the actual situation, and assumptions of radionuclide transfer coefficients are facilitated. As mentioned earlier the latter are currently poorly known for many situations, and this is so particularly for the geographical areas of interest to the canal studies. However, with the field and laboratory data along with available data in the literature, it is felt that reasonable assumptions can be made.

The overall dose estimation model provides for total radiation dose estimates, internal and external. Estimates are made for each distinct population group and for elements within each group, e.g. infants. This process of dose estimation has not yet been completed.

As mentioned throughout this discussion, a number of initial or preliminary assumptions were used in the assessment. Nuclear excavation plans may change because of various factors such as actual geological data obtained, the results of chemical analyses becoming available (12), and additional experience in test programs. Also, changes may be made in nuclear device design and thus in the radioactivity produced. As these changes are made or occur, the radiological situation must be reassessed. In fact, while it does not appear probable from information available to date, it is possible that nuclear plans may require changes to provide more favorable radiological situations.

One of the important objectives of a feasibility study is to determine where problems may exist and suggest operational solutions to them. For this reason the studies mentioned here include analyses of operational methods and techniques as integral parts of the studies. It is here that provisions are made for uncertainties in estimates. In nuclear operations plans are included facilities for detailed timely forecasts of radiological situations for each detonation and means of limiting detonations to times when situations will be most favorable from the standpoint of safety. Also, included are provisions for surveillance of situations following detonations and means for initiating countermeasures on a timely basis.

Along with the studies described here, an analysis of existing radiological protection guidance was made (10), since comparison of estimates with some guidance is necessary to an evaluation. The establishment of protection criteria for nuclear excavation of a canal is clearly beyond the scope of the canal feasibility studies, and no attempt will be made to do this. However, it is felt that the studies will be useful in this regard and some possibilities will be suggested. The approach in the canal studies has been to present the best estimates possible in a scientific manner so that a balance of the benefits and risks can be made as objectively as possible. The results will be presented so that comparison with any criteria will be possible. Perhaps the judgement involved in this balance should be among the bases of radiation protection guidance established for this and other specific applications of nuclear energy. Perhaps research, in its broader aspects, along such non-technical lines is as important as approaches to the biological effects of radiation.

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TABLE I

PRELIMINARY EXCAVATION DESIGN DATA
(ISTHMIAN CANAL STUDIES-1964)

	Route 17 (48.5 Mi.)	Route 25 (39.3 Mi.)*
No. Detonations	22	19
Devices per Row	4-38	4-45
Device Yields	200 KT - 10 MT	Same
Depth of Burial	675 - 2100 Ft.	Same
Total Yield per Row	8.4 - 30 MT	9 - 30 MT
Total No. of Devices	267	223
Total Yield per Route	292 MT	245 MT

*Total length 100 mi.

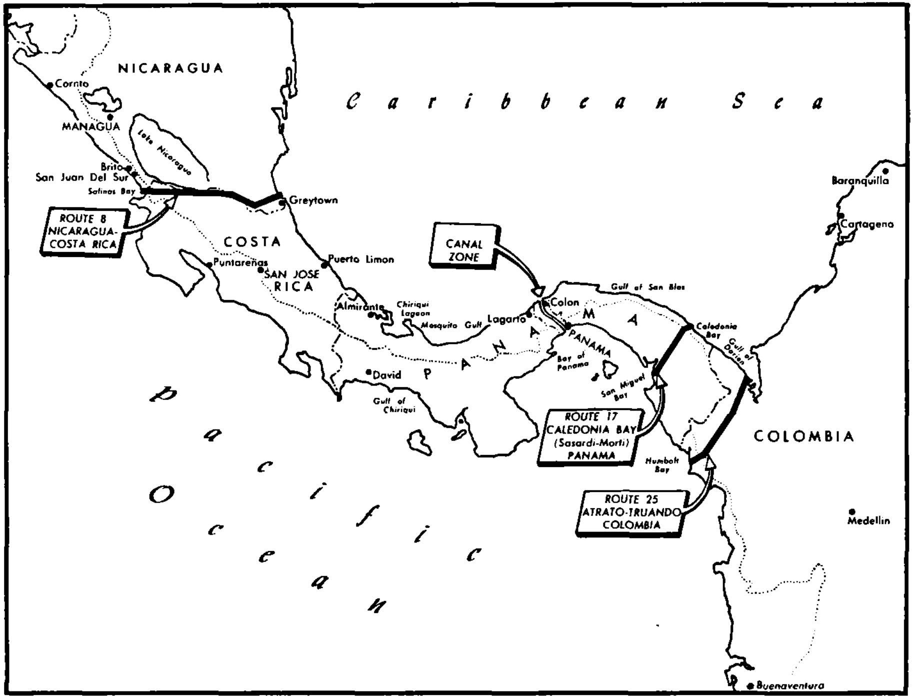

Figure 1. Proposed Sea Level Canal Routes

QUESTIONS FOR ALFRED W. KLEMENT

1. From R. M. Stewart:

   In the Route 17 canal in Panama, what portion of the excavation might be nuclear? What maximum total yield is contemplated?

   ANSWER:

   On Route 17 in the preliminary studies, it was intended that this route be excavated completely by nuclear means. We now have actual geological information on this route and this indicates that there are some problems and we are considering various methods of excavating some 20 miles of that route by a different system of nuclear excavation, a combination of nuclear and conventional, or a completely conventional means. This decision has yet to be made as there are still studies being made on it.

   The maximum total yield contemplated, and again I have to go back to the preliminary design, for any one row charge the highest was 30 megatons. This is still being considered. We would like to reduce this to the lowest we can and still do the job and there is a possibility that this would be done. But at this stage we're some ways from what actual design we have to have to excavate the canal.

2. From George Collins:

   Would you care to comment on possible adverse ecological effects resulting from a sea level canal other than the possible radiological effects? (For example - intermingling of different species of marine flora and fauna from the two oceans.)

   ANSWER:

   This, of course, is an area in which I am not competent. I can only say that a look at this problem is being made under the auspices of the Canal Study Commission by those, hopefully, who are competent. It is not an integral part of the Nuclear Safety Studies of course and it's beyond the general area you would expect our office here to undertake.

3. From E. A. Martell:

   How will physical properties of radioactive cloud debris in the wet isthmus environment compare with those for Nevada cratering tests?

   How well can debris cloud heights be predicted for large yield cratering shots in the wet isthmian environment?

ANSWER:

First of all we have no experience with large scale cratering events anywhere. This is an area we certainly need information on and to continue in a large scale project using large yields, it's essential that the experimental Plowshare program continue in order to obtain information which can be used. At the present time, we are forced to scale from the smaller shots that we have had in Nevada and materials are considerably different. Our largest test, Sedan, in alluvium was very interesting. Along Route 17, I think there is no alluvium.

With regard to the properties of the radioactive cloud, I think this is the same thing. We are still scaling from what experience we have. We certainly need, as I mentioned, experience in various environments in order to get a better handle on this.

4. From Danny T. Carrara:

Over what period of time would the 30 miles of nuclear excavation take place in Model No. 25 if this model is adopted?

ANSWER:

This would depend on the final design. Whatever system is arrived at. It would seem to me, based on our preliminary estimates, that this could be conducted perhaps over a period of 18 months, perhaps two years. Certainly, the data we have indicate that nuclear safety would not prevent us from doing this, but there are other operational problems that may. For example, with Route 25 we're talking about a total construction time for the entire canal on the order of 15 years and the nuclear excavation part of this is relatively small. The same is true of Route 17, except it is a much shorter route and will take a much shorter time.