RADIOLOGICAL ASPECTS OF A REACTOR DESTRUCTIVE TEST

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Abstract—This paper describes the radiological considerations connected with planning and conducting reactor destructive tests at the National Reactor Testing Station in Idaho. There have been, in recent years, five reactor destructive tests, including one on January 11, 1966. In the last test a modified SNAP 2/10A reactor was intentionally disassembled as a result of a nuclear excursion designed to simulate the "maximum accident" for this system. The primary radiological objectives of these tests were to determine the magnitude of the fission product release and to assess the radiation exposures resulting from the test.

This paper presents information on planning prior to the tests and a summary of the radiation exposures resulting from the releases, with special emphasis given to the SNAPTRAN-2 Destructive Test. It is shown that, by using a properly designed environmental sampling system and the statistical approach of atmospheric dispersion, one can quickly and accurately estimate the magnitude of a release. An equation is shown which is amenable to hand or computer solution and will allow estimates of the fractionation of the fission products. Many of the considerations in this paper are applicable to any test involving the release to the atmosphere of significant quantities of fission products.

INTRODUCTION

The National Reactor Testing Station (NRTS) was established in 1949 as a site where the U.S. Atomic Energy Commission could build, test and operate various types of reactors and allied plants with maximum safety. The Health and Safety Division of the Idaho Operations Office has been responsible for all environmental monitoring outside the areas specifically assigned to the operating contractors. A continuing objective of this division has been to study the behavior of fission products in the environment whenever the opportunity presents itself. Thus, it is to be expected that any discussion of the radiological aspects of reactor destructive tests at the NRTS will include a detailed description of the environmental monitoring considerations.

Due to the very nature of the NRTS, there have been numerous opportunities to study the behavior of fission products that have been released to the atmosphere as a result of both planned and unplanned events. Notable among the planned releases are the reactor destructive tests, which included the BORAX-I, three SPERT-I cores and SNAPTRAN-2 and 3. In addition there have been the direct cycle Aircraft Nuclear Propulsion reactor tests (BOOT, FEET, LIME and SUBLIME), the radioactive lanthanum (RALA) recovery process at the Idaho Chemical Processing Plant which involved the dissolution of 2–3-day-old Materials Testing Reactor fuel assemblies, operation of the Fluidized Bed Waste Calcination Facilities, and the present Controlled Environmental Radioiodine Test program (CERT). In general, the accidental releases, which include the SL-1 accident and the two criticality incidents at the ICPP, have not resulted in the release of large enough quantities of fission products to justify major research efforts.

In monitoring these fission product releases,

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many different techniques have been employed in the collection, analysis and interpretation of data. A general monitoring plan has evolved out of these efforts incorporating all of the techniques which over the years have proved of greatest value. This plan places emphasis on obtaining the maximum amount of *useful* information at a minimal cost. It is unlikely that others interested in this field of study will be able to employ the system used at the NRTS without some modification. Nevertheless, it is hoped that they will be able to utilize some of the described techniques to advantage in their research programs.

Many of the techniques used in assessing the consequences of a reactor destructive test are applicable to other types of planned or accidental releases. However, this discussion will be restricted to the considerations which go into the planning, assessment of risks, and evaluation of the consequences of a reactor destructive test resulting in a short term or "puff" release of fission products to the atmosphere.

PLANNING CONSIDERATIONS

In recent years there have been a number of tests at the National Reactor Testing Station where reactor cores have been intentionally subjected to extreme conditions, leading to partial or total destruction of the core and concommitant releases of fission products to the atmosphere. As in any field test where the quantity and quality of fission products that will be released is not known, it is vitally important that the safe conduct of these "destructive tests" be assured. This assurance can be gained by careful preplanning and by adequate test-time sampling. In those cases where environmental samples must also provide a source of information for reasons other than for safety, analytical techniques must be derived to fully utilize the gathered data.

There are two major factors that must be considered in monitoring a reactor destructive test: samples needed to determine the actual consequences of the test and the radiological test objectives. Normally, several months prior to the accomplishment of a particular test, a hazards evaluation will give a computation of the maximum as well as the expected releases. This information, with knowledge of the appropriate dose criteria, can be used to establish meteorological conditions that should be met. Sampling stations can then be placed at selected downwind locations to determine test consequences. The radiological objectives, on the other hand, determine the kind, number and location of additional samples to be taken.

On January 11, 1966, a modified SNAP 2/10A Flight-System reactor was disassembled as a result of an intentional excursion designed to simulate the "maximum accident" for this system. The radiological planning considerations in this test were typical of those for previous destructive tests. First, a safety analysis report was prepared [1] and reviewed. It was determined that there were three major objectives that influenced the type and degree of radiological monitoring: (1) to estimate the magnitude of the fission product release so that the results could be extrapolated to any situation, (2) to assess the environmental hazards resulting from the test and (3) to gather data on the behavior of fission products in the environment. On the basis of these objectives certain meteorological requirements were established in order to minimize the environmental hazards. As shown in Fig. 1, favorable meteorological diffusion conditions resulted from the combination of distance factors (distance to nearest populated area) and dose criteria (dose limits of occupational and non-occupational personnel). In addition to the general stipulation of diffusion, it was also required that winds be greater than 3 m/sec to ensure persistent directional travel and that there be no precipitation in the predicted trajectory—to ensure proper operation of sampling equipment. On the basis of the other objectives (1 and 3), only two of the sectors were preferred, allowing a single grid arrangement to be established so that optimum data recovery was possible. In these tests primary reliance was placed on the initial determination of potential radiation exposures.

If safety is the only concern, a number of monitoring stations placed at selected populated locations, plus sampling performed by mobile monitoring units who may be directed into the cloud path, will provide estimates of concentrations of fission products and thus estimates of exposures to people. If, however, estimates of the magnitude of the release and

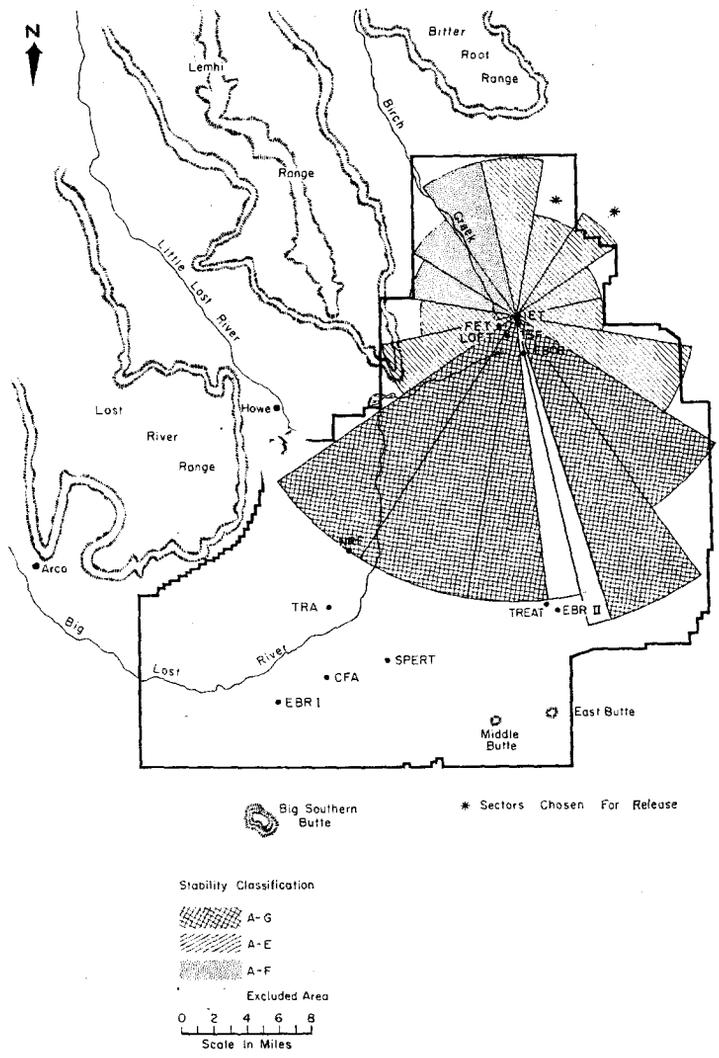

FIG. 1. Minimum meteorological requirements for the SNAPTRAN-2 destructive test, by sector.

data for research studies are desired, the sampling array must define the characteristics of the cloud.

The design of a monitoring program is to a large extent dependent upon the nature and expected consequences of the destructive test. Two different monitoring approaches will be discussed in this section. The first is the standard approach of a fully instrumented fixed monitoring grid (Figs. 2 and 3) and the second is a flexible plan which places a strong emphasis on mobility (Figs. 2 and 4). The latter approach proved extremely successful during the SNAPTRAN-2 destructive test early this year.*

Regardless of the monitoring scheme chosen,

* Monitoring for the SNAPTRAN destructive tests was a joint effort of Phillips Petroleum Company's Health and Safety Branch and the Idaho Operations Office, Health and Safety Division.

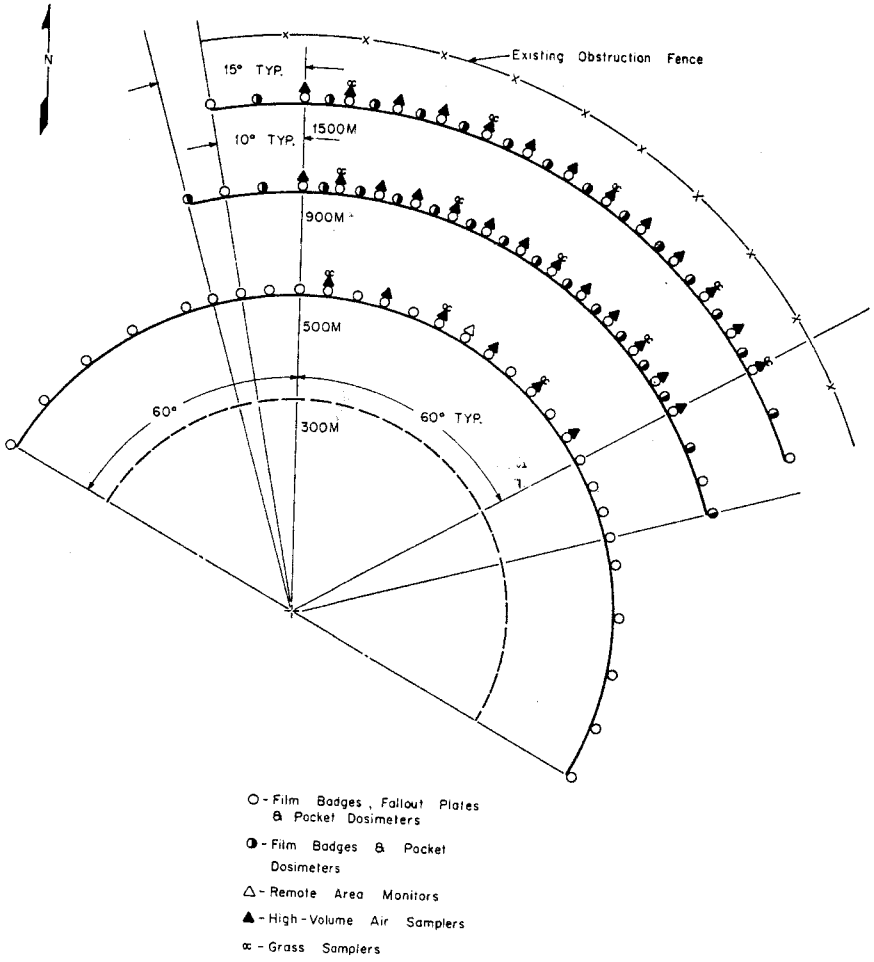

FIG. 2. Typical inner arc monitoring for the SNAPTRAN destructive tests.

there are certain features and requirements that are common to both approaches. The full support of a competent meteorological group is required to provide comprehensive weather forecasts and to monitor the weather conditions at the time of the test. In addition, this group may provide important after-the-fact information on diffusion characteristics of the atmosphere at the time of the test to aid in the analysis of fission product behavior. At the NRTS this support is provided by the Institute for Atmospheric Sciences (IAS), ESSA, which was formerly a Division of the U.S. Weather Bureau. This group has done a substantial amount of research on the meteorology of the NRTS. Also, IAS has developed a technique for tracking constant density balloons (Tetroons) by RADAR which has proved quite useful in determining the trajectories of radioactive clouds following reactor destructive tests.

Aerial monitoring is a technique that has gained wide acceptance in monitoring planned and accidental atmospheric releases of this type. Though aerial monitoring is normally not considered a test requirement at the NRTS, it has become a valuable means of obtaining early information with respect to the magnitude of the fission product release and the cloud trajectory. The instrumentation used at the NRTS is a sensitive transistorized single channel

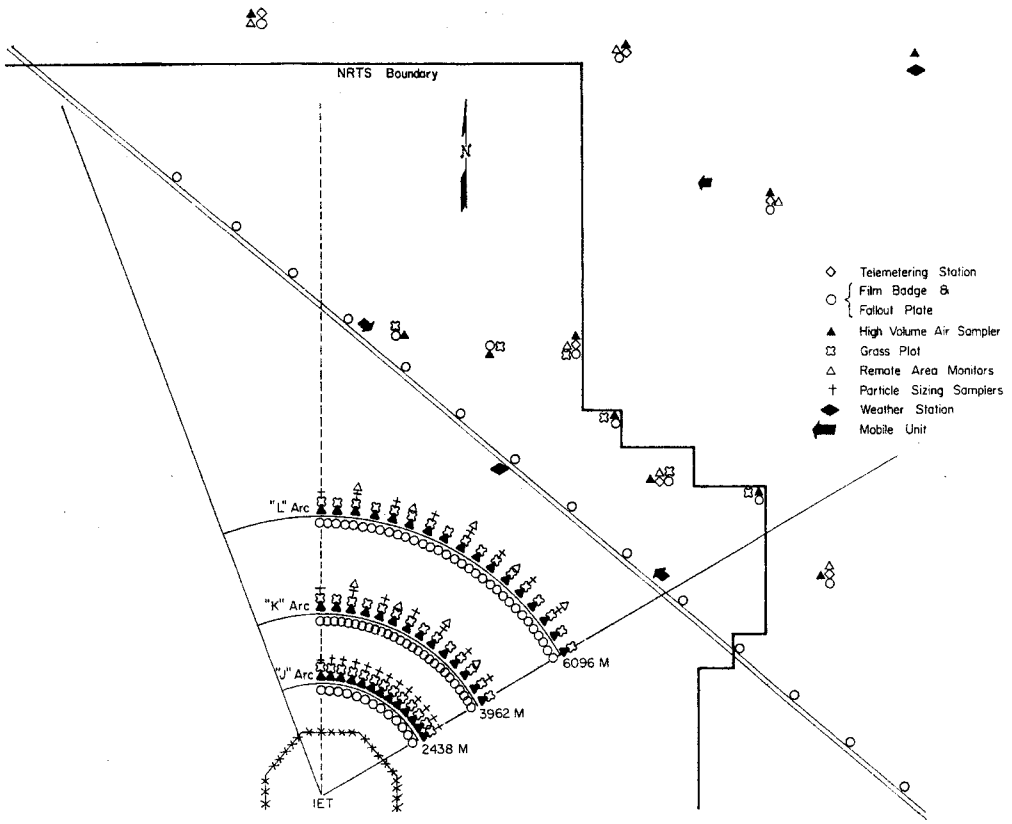

FIG. 3. Remote monitoring for the SNAPTRAN-3 destructive test.

gamma spectrometer with a strip chart recorder. However, a simple gamma scintillation survey instrument is usually adequate for monitoring releases of this type. A light single-engine aircraft with a cruising speed of 160 km/hr or more has been found to be best suited for this type of monitoring. Costs can be minimized by renting an airplane from a local flying service, as is done at the NRTS.

The off-site radiological surveillance program is normally not affected by the large research oriented on-site monitoring plan. The routine NRTS Radiation Monitoring Telemetry System forms the backbone of the off-site surveillance program, though it might be supplemented by the addition of a few stations in populated areas that are expected to be in the path of the radioactive cloud. This system is capable of measuring cloud gamma dose rate, airborne particulate activity, and airborne halogen activity. All measurements are transmitted to and recorded by the master station in the Idaho Operations Office Health and Safety Laboratory.

In designing the on-site surveillance program, the primary objective is to assure that the system will provide all of the information necessary for an early evaluation of any radiological hazards associated with the test. The required information can generally be obtained from minimal monitoring efforts within approximately 2 km of the reactor site. The most rapid means of evaluating the magnitude of the release is to measure the maximum gamma dose rate or integrated dose which can then be compared with predicted values. These measurements are normally obtained by means of one or two monitoring vehicles which are positioned in the path of the cloud. These monitoring personnel wear appropriate protective clothing and respiratory equipment. In addition to the

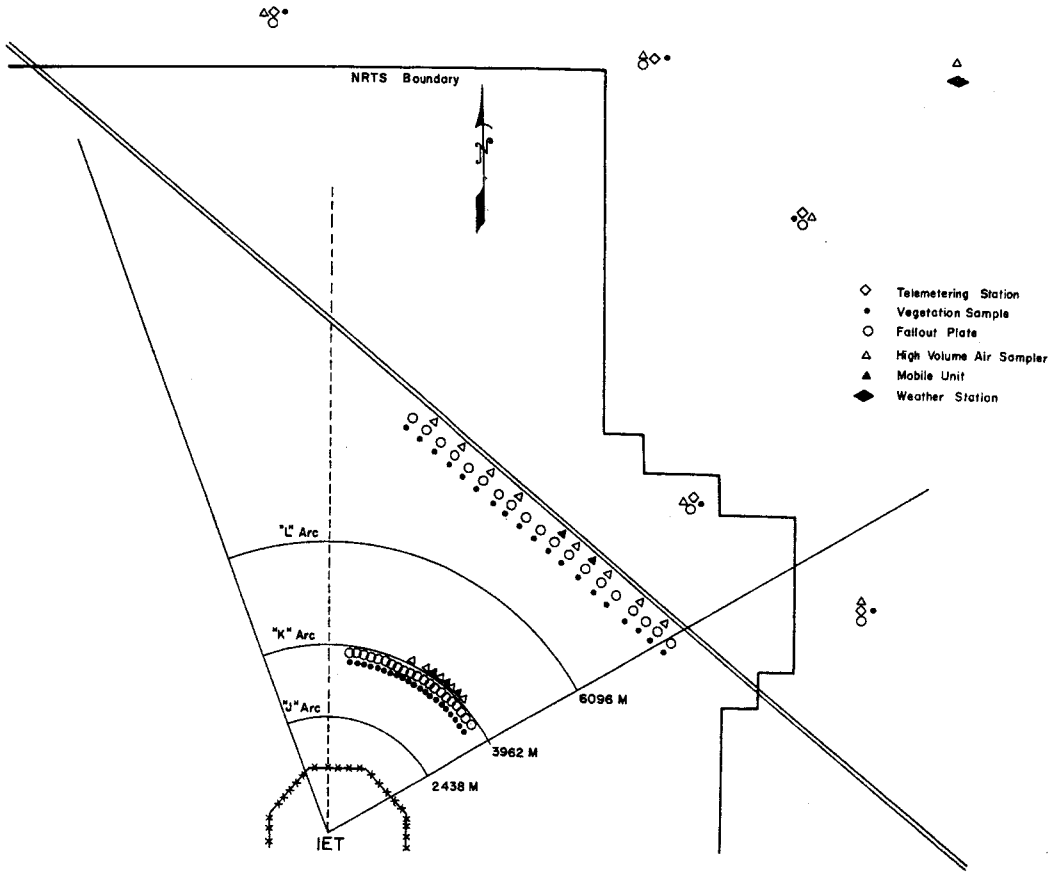

FIG. 4. Remote monitoring for the SNAPTRAN-2 destructive test.

dose measurements, these personnel are responsible for collecting the air samples which provide the earliest information on identity of the released fission products. Once the required "safety monitoring" is established, the remaining portion of the monitoring program is all related directly to the investigation of fission product behavior. Following is a list of important considerations relevant to the planning of such a monitoring system:

1. Meteorological restrictions on test
2. Types of samples required
3. Critical sampling distances
4. Desired number of sampling points in the cloud path at each distance of interest
5. Analytical support availability
6. Amount of lead time expected to be available to establish a monitoring network
7. Availability of monitoring vehicles (with and without two-way radios), and portable two-way radios
8. Inventory of portable and mobile electrical power generators
9. Availability of access roads in the area of interest
10. Terrain of the monitoring area.

Meteorological restrictions on the test generally determine the feasibility of establishing a fixed monitoring grid. If the acceptable wind direction is limited to a sector of less than 90°, a common approach has been to completely instrument three to five arcs across the entire sector. Since the area of interest may extend out ten to twenty kilometers, this becomes an extremely expensive system requiring a large quantity of monitoring equipment. A major

disadvantage of this approach, other than expense, is the amount of time and effort required to instrument such a grid. The greatest amount of time is required to establish the electrical system necessary to power the air samplers. This may involve the use of 100–150 mobile or portable generators, which would have to be positioned on the grid and routinely serviced.

The alternate system to be discussed is capable of providing the same information as may be obtained from a standard monitoring grid. This approach emphasizes mobility and close coordination between the monitoring control point, meteorological forecasting group, the aerial monitoring team and the monitoring personnel in the field. A reliable radio communications system is an absolute requirement for the successful use of this technique. Though this system can be used in place of a monitoring grid, it is particularly useful when the wind restrictions are so broad that a grid is not feasible or for distances more remote from the release point (> 2 km).

In essence, the objective of this technique is to reduce to about three hours the amount of time required to establish the monitoring network. This is done by eliminating essentially all of the air sampling and associated equipment which will not lie in the path of the cloud and is accomplished in the following manner. At test time minus three hours, a fairly accurate forecast of wind direction can be expected. Once this forecast has been received, all efforts are directed toward positioning four to five generators and air samplers on each preselected downwind arc or road in the predicted cloud path. Two or three monitoring vehicles are placed on standby on each arc as soon as the air sampling stations have been positioned. The spacing between these fixed sampling stations should be $\frac{1}{3}$ to $\frac{1}{2}$ the predicted cloud width at that particular distance. During the last few minutes prior to the test the wind direction should be firmly established and each monitoring vehicle can be moved into a gap between two of the fixed stations. This will provide a minimum of three samplers in the cloud at each distance. In the event the early wind direction forecast is incorrect, all of the monitoring vehicles can be moved to one side or the other of the fixed stations. Any wind shift after initiation of the test can be detected by the monitoring aircraft which will allow the downwind monitoring vehicles to make position corrections.

The lateral spread of the cloud can be accurately assessed by extensive vegetation sampling or by the liberal use of gummed paper or carbon coated gummed paper fallout plates if sufficient vegetation is not available. Once the ratio of airborne to deposited activity has been established at the air sampling locations, the entire lateral profile of the cloud can be inferred. The advantages of this technique include:

1. More rapid evaluation of possible hazards.
2. Minimum cost.
3. Maximum versatility.
4. Minimum impact on the analytical support laboratory.

ESTIMATING THE MAGNITUDE OF THE RELEASE

In any evaluation of the consequences of a release of fission products to the atmosphere there are two measurable parameters of value, the identity of fission products in the atmosphere and the concentration of fission products. A detailed knowledge of either of these, as a function of time and distance, must depend on an adequate estimate of the magnitude of the release.

In many cases, as with the SNAPTRAN-2 Destructive Test, there is no direct method whereby this information may be obtained. However, accurate determinations are possible from downwind air samplers.

To simplify somewhat, there are several major steps involved in estimating the total magnitude of the release:

1. Collection of samples of airborne materials.
2. Counting of samples and conversion of data to time integrated concentrations ($Ci\text{-}sec/m^3$).
3. Correcting of all concentrations to a common time.
4. Estimating the lateral spread of the cloud and the peak concentrations—at any distance.
5. Estimating the vertical dispersion and wind speed.
6. Correcting for the initial size of the cloud.

7. Correcting for materials that were not collected by the air samplers.
8. Estimating corrected peak concentrations as a function of distance to obtain the effective source at the corrected time.
9. Correcting the source to the time of the release.

Our technique of estimating the magnitude of the release stems from the use of the statistical theory of atmospheric dispersion[2] in order to account for the mass dilution of airborne material as a function of the stability of the atmosphere and the travel of this material to the point of interest. This dilution may be expressed as:

$$(1) \qquad \chi = \frac{Q}{\pi \bar{u}(\sigma_y^2 + \sigma_{yI}^2)^{\frac{1}{2}}(\sigma_z^2 + \sigma_{zI}^2)^{\frac{1}{2}}} \exp\left[-\tfrac{1}{2}\frac{h^2}{(\sigma_z^2 + \sigma_{zI}^2)}\right]$$

where $\bar{u}$ = the mean wind speed (m/sec),
σ_y = the lateral dispersion (m),
σ_z = the vertical dispersion (m),
σ_{yI} = the initial lateral dispersion (m),
σ_{zI} = the initial vertical dispersion (m),
h = the effective height of the release,
Q = the source (Ci),
χ = the time-integrated concentration at any distance of interest (Ci-sec/m^3).

If this equation is used, Q—the source term—may be determined from knowledge of the other parameters.

In actual practice, the most difficult steps in the analysis are to correct counted activity to a common time and to accurately account for materials that were not collected by the air samplers.

As indicated in a report[3] on the radiological results of the SNAPTRAN-3 (water immersion) test, a reactor transient produces large quantities of short-lived noble gases. Only the daughters of these gases are collected by the normal air samplers. This is an important consideration when estimates of cloud concentrations must be determined from collected activity for samples at small distances (< 2000 m).

The calculation of cloud activity may be computed from the following equations:

(2) *First Isotope*

$$N_1(t) = N_1(0) \exp[-\lambda_1 t]$$

(3) *Second Isotope*

$$N_2(t) = \frac{N_1(0)\,\lambda_1}{(\lambda_1 - \lambda_2)}\left[\exp[-\lambda_2 t] - \exp[-\lambda_1 t]\right] + N_2(0) \exp[-\lambda_2 t]$$

(4) *Third Isotope*

$$N(t) = \frac{N_1(0)\,\lambda_1\lambda_2}{(\lambda_1-\lambda_2)(\lambda_1-\lambda_3)(\lambda_2-\lambda_3)}\left[(\lambda_2-\lambda_3)\exp[-\lambda_1 t] - (\lambda_1-\lambda_3)\exp[-\lambda_2 t] + (\lambda_1-\lambda_2)\exp[-\lambda_3 t]\right] + N_2(0)\frac{\lambda_2}{(\lambda_2-\lambda_3)}\left[\exp[-\lambda_3 t] - \exp[-\lambda_2 t]\right] + N_3(0)\exp[-\lambda_3 t]$$

where $N_i(t)$ = number of atoms of ith isotope at time t after excursion,
λ_i = radioactive decay constant of ith isotope,
$N_i(0)$ = initial atoms produced of ith isotope.

As this cloud passes by an air sampler at time T (and assuming the noble gas is the precursor to the chain), the equations must be modified to calculate collected activity, as shown in the next examples.

(5) *First Isotope*

$$N_1'(t) = 0 \qquad t \geq T$$

(6) *Second Isotope*

$$N_2'(t) = N_2(T) \exp[-\lambda_2(t-T)]$$

(7) *Third Isotope*

$$N_3'(t) = N_2(T)\frac{\lambda_2}{(\lambda_2-\lambda_3)}\left[\exp[-\lambda_3(t-T)] - \exp[-\lambda_2(t-T)]\right] + N_3(T)\exp[-\lambda_3(t-T)]$$

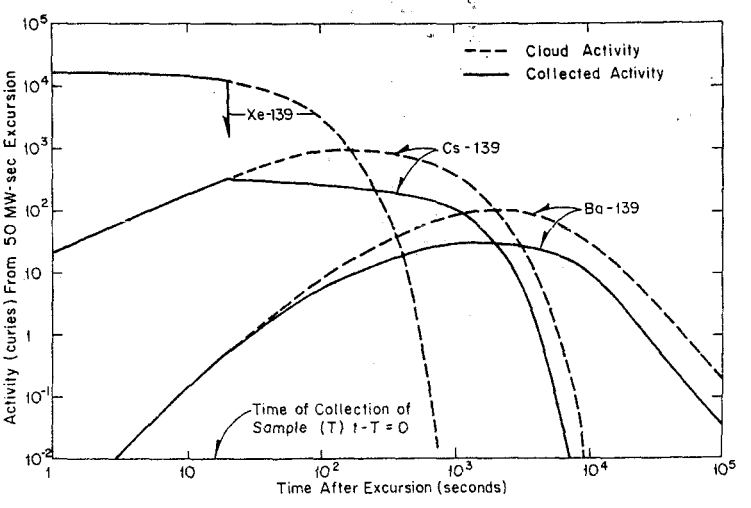

FIG. 5. Comparison of cloud activity and collected activity when the precursor of a decay chain is not collected.

Thus the correction factors may be obtained from $N_i(t)/N_i^1(t)$. The importance of this correction is shown in Fig. 5. In this example an estimate of released Xe-139 based on counted Ba-139 would underestimate the true value by a factor of seven.

Before estimates of peak concentrations can be attempted, the counted activities must be corrected to a common time. This may be accomplished by two methods. If sequential counts are taken from representative samples at each distance, the peak concentrations at each distance may be easily estimated, by fitting a Gaussian distribution to the corrected data points (Fig. 6). The lateral diffusion, σ_y, is that strong-wind distance where the concentration is 0.6 that at centerline. With values of $\bar{u}$ and σ_z from meteorological data, the source term at the count time may then be determined. This can be compared to the amount produced to estimate fractional release.

Alternately, all samples can be corrected to the same count time, once corrections for the non-collection of nobles have been made. This was done in analyzing the results of the SNAPTRAN-2 Destructive Test. With that data a curve of peak concentrations as a function of

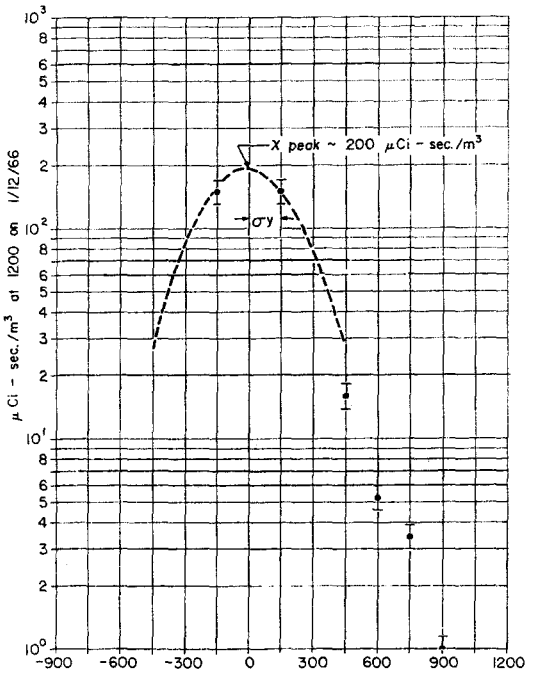

FIG. 6. Derivation of peak concentrations from measured crosswind concentrations.

distance can be derived to find both the magnitude of the release and the initial height and size of the release. As shown in Fig. 7, the estimates using this approach compare very favorably with observed results. In this case, estimates of Q can be obtained from values of the other factors at any point of interest. From the equation and parameters listed in Fig. 7, a release fraction of 25% of that produced is indicated for the SNAPTRAN-2 Test.

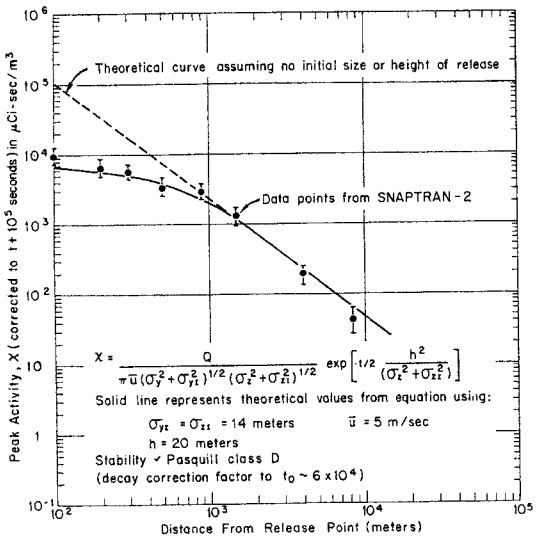

FIG. 7. Comparison of actual and predicted peak concentrations.

Before the consequences of the release can be adequately assessed, knowledge of the release of each chain or of groups of chains (e.g. nobles, halogens) must be obtained. This can be obtained from isotopic analysis of the collected activity—such as by gamma spectrometric analyses. The actual fractionation can be solved by a series of simultaneous equations:

(8) *Fractionation of the Parent*

$$F_1\ A_{11} = A^*_1$$

(9) *Fractionation of Two-membered Chains*

$$F_1\ A_{21} + F_2\ A_{22} = A^*_2$$
$$F_2\ B_{22} + F_2\ B_{22} = B^*_2$$

(10) *Fractionation of Three-membered Chains*

$$F_1\ A_{31} + F_2\ A_{32} + F_3\ A_{33} = A^*_3$$
$$F_1\ B_{31} + F_2\ B_{32} + F_3\ B_{33} = B^*_3$$
$$F_1\ C_{31} + F_2\ C_{32} + F_3\ C_{33} = C^*_3$$

(11) *Fractionation of Four-membered Chains*

$$F_1\ A_{41} + F_2\ A_{42} + F_3\ A_{43} + F_4\ A_{44} = A^*_4$$
$$F_1\ B_{41} + F_2\ B_{42} + F_3\ B_{43} + F_4\ B_{44} = B^*_4$$
$$F_1\ C_{41} + F_2\ C_{42} + F_3\ C_{43} + F_4\ C_{44} = C^*_4$$
$$F_1\ D_{41} + F_2\ D_{42} + F_3\ D_{43} + F_4\ D_{44} = D^*_4$$

where A, B, C, D refer to 4 chains that are expected to behave similarly (I-131, I-132, I-133, I-135),

F_j is the fraction released of each isotope in the chain (F_1—fraction released of parent) and assumes no isotopic differences in fractionation; $F_{I\text{-}132} - F_{I\text{-}132}$,

A_{ij} indicates the expected activity of the ith isotope from the amount of the jth isotope that was initially produced,

A^*_i is the counted activity of the ith isotope *corrected for diffusion.*

As can be seen this determination may be simply described as:

$$A^*_i = \Sigma F_j A_{ij} \tag{12}$$

or taking the data from the point of concentration

$$A^*_i = \chi_i\, \pi \bar{u}\, (\sigma_y^2 + \sigma_{y_1}^2)^{\frac{1}{2}}\, (\sigma_z^2 + \sigma_{zI}^2)^{\frac{1}{2}} \exp\left[\tfrac{1}{2}\, \frac{h^2}{(\sigma_z^2+\sigma_{zI}^2)}\right] \Sigma F_j A_{ij} \tag{13}$$

where χ_i is the time integrated concentration of the ith isotope at the point of interest.

Equation (13) can be solved either by hand calculations or by computer techniques using tabulated values of inventories.[4,5] Use of key equations (1) and (13) allows rapid and accurate evaluations of the magnitude and kind of release to the atmosphere. These can be used to provide rapid estimates based on initial results or to provide more accurate estimates when all data has been analyzed.

By the use of the techniques shown earlier the magnitude and fractionation of fission product releases in five recent reactor destructive

Table 1. *Release Estimates*

	SPERT-I			SNAPTRAN-3	SNAPTRAN-2
	Test I	Test II	Test III		
Total release (Ci)	1.8×10^4	4×10^2	1×10^3	3.2×10^4	2×10^6
% release	0.36	1.5×10^{-3}	3.9×10^{-3}	0.4	20
% nobles	3.6	1.5×10^{-2}	3.8×10^{-2}	4	75
% iodines	$< 5 \times 10^{-3}$	$< 1 \times 10^{-2}$	$< 1 \times 10^{-2}$	$< 2 \times 10^{-2}$	70
% tellurium	—	—	—	—	45
% others	$< 5 \times 10^{-4}$	$< 1 \times 10^{-3}$	$< 1 \times 10^{-3}$	$< 2 \times 10^{-2}$	5

Table 2 indicates significant factors in the test that have importance in evaluating this release data.

tests including SNAPTRAN-2, have been estimated. The results are shown in Table 1, which also gives information on the percent of the core inventory that was released.

All the tests, except SNAPTRAN-2, were conducted with the reactor immersed in water at ambient temperature and pressure. Also, all tests were conducted with no significant inventory previous to the transient.

There are two factors of immediate interest, the scrubbing effect of water and the fractionation of fission products. These scrubbing factors appear to be of the order of 10^3 for iodines and 10^4 for solids. The fractionation of SNAPTRAN-2 seems, as expected, to follow the relative volatility of the fission products.

With data on releases and fractionation it is possible to extrapolate the actual consequences of the tests to any given set of meteorological conditions or to any location where samples were not taken.

EVALUATION OF ENVIRONMENTAL HAZARDS

There are essentially three phases of hazards evaluation: (1) Pretest evaluations to determine the feasibility of test operations and to define the desired meteorological conditions; (2) Early estimates of test consequences based on initial results; and (3) Final estimates based on a detailed knowledge of the release.

Since the results of a destructive test cannot be completely guaranteed prior to its initiation, it is important that data gathered soon after a release be evaluated to define the actual consequences to off-site areas.

A rough estimate of the total magnitude of the release can be obtained from an estimate of the peak concentration at any given distance (as shown in Fig. 7) and an estimate of the diffusion to that distance for a stability category representative of test-time conditions (as, for example, from ref. 6). This can normally be obtained

Table 2. *Reactor Test Data*

	SPERT-I			SNAPTRAN-3	SNAPTRAN-2
	Test I	Test II	Test III		
Fuel type	U-Al alloy	UO_2	UO_2	Zirconium-hydride 10 weight % U	Zirconium-hydride 10 weight % U
	Plate	Pin	Pin	Pin	Pin
Clad	Al	SS	SS	Hastelloy-N	Hastelloy-N
Enrichment (%)	93.5	4	4	Fully enriched	Fully enriched
Mw-sec	30.7	155	165	45	54

Table 3. Summary of Off-site Doses from the SNAPTRAN-2 Destructive Test (rem)

	Criteria[1]	Pretest estimates[2]	Early estimates	Actual
Thyroid — Ingestion	5×10^{-1}	4.4×10^{-2}	10^{-1}	3×10^{-2}[3]
Inhalation		1.3×10^{-3}	3×10^{-4}	10^{-4}
Whole body	1.7×10^{-1}	6.6×10^{-4}	3×10^{-4}	3×10^{-4}
Bone	5×10^{-1}	1.1×10^{-4}	—	$< 10^{-4}$

[1] From ref. 10.
[2] From ref. 1.
[3] Potential dose—no cows known to be grazing.
All calculations except thyroid ingestion based on ICRP[7] standard man.

within a few hours after the release. With gamma spectrometric analyses of a few samples, a fairly good approximation of off-site concentrations of airborne materials can be obtained. Milk and vegetation samples provide a continuous check on possible ingestion dose.

After the data have been more completely analyzed, accurate estimates of test consequences can be made. Comparisons of the three phases of dose estimates for SNAPTRAN-2 with relevant criteria are shown in Table 3.

SUMMARY AND CONCLUSIONS

By use of an environmental sampling system which provides values of peak concentrations as function of distance, and by proper analytical techniques, it is possible to obtain reliable and accurate estimates of the total magnitude of a release to the atmosphere and a detailed knowledge of the isotopic concentrations of airborne materials. These results can then be extrapolated to any point of interest or for any given set of meteorological conditions. These techniques have been of value in evaluating the results of five destructive tests at the National Reactor Testing Station and may be applied to any similar situation where estimates of fission product releases are desired.

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REFERENCES

1. W. J. Neal (ed.). Safety Analysis Report, SNAPTRAN 2/10A-1 and 2, Safety Tests Revision 2, IDO-17076, October 1965.
2. W. F. Hilsmeir and F. A. Gifford. Graphs for estimating atmospheric dispersion. ORO-545, 1962.
3. O. L. Cordes *et al.* Radiological Results of SNAPTRAN 2/10A-3, Destructive Test, IDO-17038, January 1965.
4. D. B. Kochendorfer. Calculated activities of U-235 fission products for very short nuclear reactor operation. USNRDL-TR-757 Volumes I and II, June 1964.
5. R. L. Coates and N. R. Horton. RSAC-A Radiological Safety Analysis Computer Program, IDO-17151, May 1966.
6. G. R. Yanskey *et al.* Climatography of the national reactor testing station. IDO-12048, January 1966.
7. International Commission on Radiological Protection, *Radiation Protection*, Recommendations of the International Commission on Radiological Protection, ICRP-2. Report of Committee II on Permissible Dose for Internal Radiation. New York, Pergamon Press, 1959.
8. D. F. Bunch. Spert I Destructive Test Series. Environmental Monitoring and Research Studies, IDO-12039, January 1965.
9. O. L. Cordes *et al.* Radiological Aspects of the SNAPTRAN-2 Destructive Test, IDO-17203. February 1967.
10. U.S. Atomic Energy Commission Manual, Chapter 0524, "Standards for Radiation Protection", 1963.