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A Paper Prepared for Presentation
at the
International Symposium on
Fission Product Release and Transport
Under Accident Conditions
Oak Ridge, Tennessee
April 5, 6, and 7, 1965

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Ref. File: On Fission Product Release
FOLDER Fission Product Dispersion and Release from the SNAPTRAN 2/10A-3 Destructive Test

Work performed under the auspices of the
U. S. Atomic Energy Commission
(Contract AT(10-1)-205)

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FROM THE SNAPTRAN 2/10A-3 DESTRUCTIVE TEST

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A B S T R A C T

The destructive test of a SNAP 10A/2 reactor by water immersion as part of the aerospace nuclear safety (SNAPTRAN) studies being conducted by Phillips Petroleum Company for the Atomic Energy Commission provided a rare and unusual opportunity to study the release and distribution of fission products from a full scale reactor destruction under accident conditions.

The reactor destructive experiment conducted on April 1, 1964, consisted of a modified SNAP 10A/2 flight system reactor mounted in a large water filled concrete tank. The reactor core contained essentially virgin fuel consisting of 37 zirconium hydride fuel rods formed into a close packed hexagonal array containing 4.75 Kg of U-235 and 464 gram moles of hydrogen. NaK coolant filled the interstitual spaces between the fuel rods. Six beryllium inserts shaped the core into a cylinder approximately 9 inches in diameter and 13 inches high. The reactor was held sub-critical by a binal sleeve until the test was initiated at which time the binal sleeve was removed by a piston driven by a black powder charge.

Fission product release and distribution data were obtained from fuel remains, environmental water samples and from a radiological monitoring grid populated with a variety of sampling devices including high volume air samplers modified for iodine monitoring, fallout plates, fission gas detectors and particle size samplers. Air sampler filters were analyzed for fission products by non-destructive gamma ray analyses, fuel and water samples were subjected to radiochemical separation before analyses.

Fission products detected on the grid consisted entirely of daughters of noble fission gases (3 sec Kr-92, 10 sec Kr-91, 16 sec Xe-140, 41 sec Xe-139, and 17 min Xe-138). The Cs-138 daughter of 17 min Xe-138 was detected in a fission gas detector designed to hold the longer lived gases for decay. From the lack of any fission products other than daughters of short lived noble gases it was concluded that only noble gases were released to the surrounding atmosphere. Halogens and solid fission products remained in the fuel and environmental water.

Fission product release data obtained from the grid were corrected for the portion of each decay chain that was not sampled because the fission product parent was in a gaseous form. These corrected amounts were used to determine the lateral cloud diffusion and the peak isotopic concentration at each grid. These concentration values were used to

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predict a fission cloud release model that would fit the observed data. The release model was then combined with a Sutton type diffusion equation to obtain the quantity of the fission products released from the reactor.

Efforts to determine the distribution of the radioiodine lead to the conclusion that the majority of the iodine remained in the fuel with the remainder being either absorbed in the environmental tank water or plated out on the concrete walls.

The general conclusions reached regarding the release of toxic and radioactive materials to the environment as a result of the destructive excursion of the reactor were as follows:

1. More than 99% of the fission products were retained in the environmental water and reactor fuel remains.

2. Halogens released from the fuel were retained by the environmental tank water with the result that no dectable iodine was released to the radioactive cloud.

3. The radioactive cloud contained only noble fission gases and their daughters. Calculations indicate that the noble gas release fraction was less than 4% of the total noble gas inventory.

Although the SNAP 10A/2 reactor used in this test is not representative of conventional power reactors, the information obtained is useful for evaluating analytical models.

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I. INTRODUCTION

As part of the space effort of the United States, a number of small nuclear reactors are under development to supply auxiliary power for space vehicles. These SNAP (Systems for Nuclear Auxiliary Power) reactors, which cannot be provided with the usual engineering safeguards, because of weight limitations, pose unique nuclear safety problems. The Atomic Energy Commission, therefore, has established, as part of its overall nuclear safety effort, a test program to determine the radiological consequences of potential nuclear incidents involving these reactors under actual accident conditions. This testing program, which is being conducted for the Atomic Energy Commission by Phillips Petroleum Company at the National Reactor Testing Station (NRTS), has been designated the SNAPTRAN Program, with the first reactor testing being the SNAP 10A/2.

At 1144 hours on April 1, 1964, the Engineering Test Branch (ETB) of Phillips Petroleum Company initiated a destructive excursion with a SNAP 10A/2 reactor to simulate a water immersion type of accident. This test was designated as the SNAPTRAN 2/10A-3 Water Immersion Destructive Test.

The purpose of this paper is to present the radiological data concerning the release and spread of fission products obtained from this simulated reactor accident.

II. DESCRIPTION

The reactor destruction experiment consisted of a modified SNAP 10A/2 Flight System reactor mounted in a large water filled concrete tank (Figure 1). The reactor core as shown in the cross section view of Figure 2, was composed of six beryllium inserts and thirty-seven fuel rods arranged in a close-packed hexagonal array containing 4.75 kg of U-235 and 464 g-moles of hydrogen. The fuel rods consisted of an alloy of zirconium hydride and 10 weight percent of fully enriched uranium, clad with hastelloy-N. The fuel rods and beryllium inserts formed a cylinder approximately 9 inches in diameter by 13 inches long and were contained in a thin-walled stainless steel vessel. NaK coolant filled the interstitual spaces between the fuel rods.

The reactor was controlled by the axial position of a 1/4 inch thick neutron absorbing binal sleeve which surrounded the reactor. Initiation of the destructive excursion was accomplished by removing the binal sleeve with a pyrotechnic actuator. The pyrotechnic actuator, powered by a black powder charge, removed the control sleeve from the reactor at velocities comparable to those at which the reactor would enter the water from a launch abort. Under these conditions, the destructive test approached the maximum credible accident for a water immersion incident.

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III. MONITORING NETWORK

Fission product release and distribution data were obtained from fuel remains, environmental tank water samples and from samples recovered from an extensive radiological monitoring grid.

The monitoring grid consisted of a series of concentric arcs with the reactor test pad as the center. A heavy concentration of sampling equipment was placed in a 60° sector, oriented with the centerline of the proposed "cloud trajectory 30° east of true north". The types of samplers used and the placement of the instrumentation on the monitoring grid are shown in Figures 3, 4, and 5, with a typical grid station shown in Figure 6.

Responsibility for monitoring the radioactive fission product release was divided between Phillips Petroleum Company Health and Safety Branch and the Health and Safety Division of the USAEC Idaho Operations Office. Phillips Petroleum Company provided monitoring out to approximately 1600 meters and ID Health and Safety provided monitoring beyond 1600 meters. The U. S. Weather Bureau was responsible for determining the atmospheric diffusion conditions and that the following meteorological conditions were met:

1. Lapse (unstable) conditions, to persist a minimum of three hours after the test to insure adequate diffusion conditions

2. Mean wind direction in the sector between 180 and 240°, with the allowance of an additional 20° on each side of the sector for short term wind fluctuations to assure passage of the cloud over the instrumented grid.

3. Wind speed between 10 and 30 miles per hour, the lower limit to insure reliability for forecasting a persistent wind direction and the upper limit to assure safe aerial monitoring

4. No precipitation in the area, in order to maintain good sampling conditions and to prevent localized washout of radioactive material.

IV. MONITORING EQUIPMENT

Air samplers used on the grid were Staplex hi-volume samplers modified to draw air through a four-inch-diameter particulate filter backed by a standard one inch deep iodine-collecting charcoal cartridge Figure 7. With this arrangement, the average flow rate through these samplers was approximately 22 cfm. Some of these samplers were modified to obtain greater flow rates (approximately 40 cfm) by enlarging the inlet side of the sampler to hold two four inch diameter filters, each backed by a charcoal cartridge.

Filtering media consisting of commercially available spun poly-

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styrene pads (Microsorban) were used on all particulate air samplers during the test. This material had the advantage of low flow resistance while maintaining a high collection efficiency (greater than 99 percent for particles greater than 0.4μ). In addition, the filters made from this media contained no beryllium, which made them useful for beryllium monitoring.

Noble fission gas detectors, utilizing balloons for delay tanks, were designed and used at a number of grid stations to sample the radioactive noble gas concentration in the cloud.

Three types of particle size samplers were used in the downwind sector of the grid to obtain particle size information. These were the two stage cyclone sampler, the Unico cascade impactor and the Anderson sampler.

Deposition sampling was accomplished with fallout plates located at each grid station. These fallout plates were made from a sticky transparent paper mounted on ridged steel frames. Large size plates, 12 x 15 inches, were used in close to the reactor to obtain a highly sensitive measurement. Smaller plates 4 inches by 9 inches were used where large numbers were required.

Direct radiation measurements of the fission product laden cloud were obtained using personnel film dosimeters of the type used at the NRTS (Dupont film packets) and remote area monitoring ion-chamber type monitors. Beta exposure measurements from film dosimeters located on a tower and on the test pad exhaust stack were used to measure the height of the cloud while direct radiation dose rate measurements from the remote area monitors were used to obtain information about the cloud passage time.

In addition to instruments for obtaining fission product release data other instruments were installed on the grid for measuring direct radiation dose rates and effects. In particular a 25 unit telemetering system was used with the 25 units dispersed on the 1500 and 2500 meter arcs. These units reporting to a remote control center, two miles away in the Technical Support Area, provided immediate information regarding the severity of the release.

V. TEST OPERATION

Count down procedures for preparation of the radiological monitoring network began at 0600 hours on the morning of April 1. Field crews from each of the three monitoring organizations drove to their assigned areas and began preparing the sampling stations for the test. Portable generators and high volume air samplers on the arcs beyond 300 meters were started, fallout plates and film badge dosimeters were placed in test position, and other sampling devices, such as water catch cans and fission-gas detectors, were made ready at their respective locations. Monitoring trailers, which also served as communication control centers, were placed at the edge of the 60° sector of the grid in preparation

for receiving and dispatching samples recovered from the grid following the test. Each responsible group had two-way radio contact between field crews, reactor test personnel, and their respective control centers. By 1030 hours, all grid stations had been activated and the grid area out to 1600 meters had been cleared of personnel. Air samplers on the inner arcs (from 25 to 300 meters), scheduled to operate for four minutes, were started at 30 seconds prior to the initiation of the test. Count down procedures continued without incident until 1144 hours, when the destructive excursion was initiated.

Within milliseconds following the initiation of the reactor excursion, steam and water were ejected from the environmental tank in a spherically shaped cloud. The cloud maintained its symmetrical shape for a short time during which most of the water collapsed back into the environmental tank. Following the collapse of the water, a visible, vapor-filled cloud blew downwind over the heavily instrumented sector of the monitoring grid. Telemetered data from the 2500-meter arc provided immediate information that the radioactivity release had been small and that no significant radiation hazard had been created.

Following the destructive excursion, the senior staff of the Engineering and Test Branch evaluated the condition of the reactor using TV cameras, water level indicators, and nuclear radiation detectors to determine that the reactor remains were in a safely shutdown condition. Approval was given for the re-entry team to enter the test cell area at 1220 hours. Direct radiation readings of 150 mr/hr were encountered at the test cell entrance and a maximum of 400 mr/hr was recorded adjacent to the environmental tank. The team made a brief inspection of the test area and the environmental tank and returned to the underground change room where they were surveyed for contamination. Low level activity (1.0 mrem/hr) was detected by a GM portable survey instrument on the soles of the shoe covers worn by the re-entry team, which indicated that the reactor test pad was only slightly contaminated.

At approximately 1240 hours, sample recovery teams, began retrieving samples from the radiological grid and from around the reactor test pad. All samples to be analyzed for short-lived activity were collected by 2000 hours. Other nonpriority samples were collected the following day. Samples collected from the grid were checked through the sample recovery trailers, sealed in plastic bags, and routed to those responsible for the analyses.

VI. FISSION PRODUCT DISTRIBUTION

Fission products from the test were distributed among the radioactive cloud, the water in the environmental tank, and the solid remains of the reactor fuel. Measurements were made on each of these three items in order to determine the isotopic distribution of the fission products from the test.

1. Fission Products in Cloud

Only daughters from short lived noble gas fission products (3-sec Kr-92, 10 sec Kr-91, 16 sec Xe-140 and 41 sec Xe-139) were collected by particulate samplers sampling the cloud. In addition, the barium daughter of Xe-139 was detected on charcoal cartridges in the air samplers, and the cesium daughter of 14 min Xe-138 was collected by fission gas detectors.

1.1 Particle Size and Deposition

Careful analysis of the fallout plate deposition samplers by both radiochemistry and by gamma ray counting showed that upwind and downwind plates had collected the same trace levels of activity which was taken to be background activity.

Particle size samplers out to 1600 meters likewise did not collect sufficient activity to permit an analysis of the particle size distribution of the released fission products. Only the backup filters of the Cyclone samplers collected sufficient activity for analysis and these merely indicated that the particles were smaller than the 10 μ cut off range of this sampler. Autoradiography of the high volume air-sampler filters showed a very smooth, even distribution indicating that the particles associated with the radioactivity were small and well dispersed.

1.2 Cloud Radiation

Direct radiation from the cloud was measured by remote radiation monitors, film dosimeters, and film dosimeters located in "wells". The downwind film-dosimeter exposures indicate that the cloud passed down the center of the grid directly over the five remote radiation monitors located on the centerline of the 60° sector of the radiological grid. The measured dose rates from the detectors are shown as a function of time and distance in Figure 8. The traces show a small response to the prompt gamma radiation, followed by a decay of the delayed gamma radiation prior to the arrival of the cloud.

The "well" film dosimeters, being shielded from the reactor, saw only the direct radiation from the cloud. The maximum recorded radiation dose from the cloud occurred within 25 meters of the reactor. Three "well" stations on the 25-meter arc recorded total beta-gamma doses of 240 mrem, 460 mrem, and 290 mrem, respectively. One hundred meters from the reactor, the maximum dose from the cloud, as measured by a "well" film-badge dosimeter, was 35 mrem. Cloud dispersion and radioactive decay were such that film dosimeters at all grid stations, 300 meters or more from the reactor, recorded less than 25 mrem, total dose.

A monitoring airplane intercepted the main cloud at approximately one mile from the test site and followed it for twenty-one miles before cloud dispersion and radioactive decay reduced the radiation levels to background. At eleven miles from the test site, the airplane measured a peak reading of 0.1 mrem/hr while flying at approximately 1200 feet above the terrain.

2. Fission Products in Water

Samples of water expelled during the excursion were captured in catch cans and water trays. Samples of the water remaining in the environmental tank were obtained two days following the test from an undergrcund "hot waste" storage tank. Of the 10,000 gallons of water originally in the tank, all but about 500 gallons returned to the tank following the initial power burst. Specific analysis for Ce-141, I-131, Ba-La-140 and Zr-Nb-95 were performed. The water expulsed during the excursion contained significantly higher concentration of Ce-141 than did the water remaining in the tank while just the opposite was true with I-131. The Ce-141 would indicate that its parent Xe-141 was released from the fuel in time for it to be trapped in the water that did not return to the tank. The I-131 ratio indicates that the tellurium parent was held in the fuel. The iodine was not released until after the excursion. In addition to the isotopes listed, large quantities of activated sodium (Na-24) and trace quantities of Ru-103, Ce-143, Np-239, Te-132, I-132, and I-133 were detected in the environmental tank water.

3. Fuel Analysis

3.1 Radiochemical Analysis For Fission Products

Because of the problems connected with recovering radioactive fuel and in preparing suitable sample specimens for radiochemical analysis, the fuel analysis was not started until nearly one month following the test. Because of this relatively long time interval, only the longer-lived isotopes could be quantitatively measured.

Four samples from each of three fuel pins were analyzed for I-131, Ba-La-140, Ce-141, Zr-Nb-95, Cs-137 and Sr-89. In addition one fuel pin sample was analyzed for Kr-85 to measure the quantity of noble gas retained.

3.2 Fragmentation

Fission product sampling of the various fuel sizes, while not completely rigorous because of difficulties in obtaining representative samples, showed a trend towards higher levels of activity in the more finely divided fuel. While the reason for this trend is not completely clear, it can be posutlated that in part it was due to the finer particles coming from the regions of the core having the highest flux.

Table I shows the approximate size range and quantity of the reactor fuel following the test. Essentially all of the fuel was contained within the environmental tank.

TABLE I

FUEL PARTICLE SIZE RANGE

Particle Size Range	Grams[a]	Total Grams Prior to Test	Percent Recovered
Less 74 microns	13.0		
74 to 149 microns	74.9		
149 to 1,000 microns	1,015.17		
1,000 to 4,760 microns	2,776.0		
Greater 4,760 microns	53,335.93		
Total	57,215.00	57,720	99.2

(a) Includes fuel, cladding, and end caps.

VII. DATA ANALYSIS

A number of conclusions can be drawn from the destructive test data; some of which, including the distribution of radioactive iodine, and the fraction of fission products released to the atmosphere, are explored in this section.

1. Iodine Distribution

Because of its potential biological effect a great deal of interest has developed in the release of iodine from damaged reactor fuels, especially in fuels ruptured under accident conditions. For this reason an attempt was made to account for the iodine produced during the destructive excursion.

1.1 Available Iodine

The number of curies of various iodine isotopes which were produced during the destructive excursion and were, therefore, available for release to the atmosphere at the time of the test are shown in Table II.

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TABLE II

CURIE CODE DATA FOR IODINE

Conditions:	
Generation Time	4 msec
Energy Release	50 MW-sec
Decay Time	0 sec

Isotope	$T\frac{1}{2}$	Curies Available
I-129	10^7 yr	1.0×10^{-17}
I-130	----	----
I-131	8.05 day	0.16
I-132	2.3 hr	1.4×10^{-7}
I-133	20.8 hr	3.4×10^{-6}
I-134	52.5 min	77
I-135	6.7 hr	47
I-136	86 sec	1.1×10^4
I-137	24.4 sec	6.1×10^4
I-138	6.3 sec	1.6×10^5
I-139	2 sec	2.7×10^5

These quantities were calculated with the CURIE computer code, using a fission-product generation time of 4 msec and a total energy release of 50 megawatt seconds. A more refined estimate now indicates that the energy released during the test was on the order of 45 ± 4 megawatt seconds. In addition, the core had experienced an energy release during prior power calibrations of 13.1 megawatt seconds. However, since the power calibrations were spread over several months the iodine contribution from this source was negligible.

1.2 Iodine Released to the Cloud

Although much of the grid instrumentation was orientated

towards highly sensitive detection of airborne radioactive iodine, iodine was not detected in the radioactive cloud.

The minimum concentration of iodine detectable by the sampling and counting system under test conditions was 2.98×10^{-7} μc/cc. This assumes 100 percent collection efficiency for the charcoal bed, a cloud sampling time of 10 seconds, and a sampling rate of 20 cfm. Using an estimated upper-limit cloud volume of 4.17×10^{4} m^3, this concentration yields an estimated upper-limit of 0.012 curies of iodine that could have been released without detection. This corresponds to approximately 0.03 percent of the available iodine-135. The results of the field measurements and the sensitivity calculations indicate that the iodine release from the destructive excursion, if any, was insignificant.

1.3 Iodine Released to the Water

Radiochemical analysis of the environmental tank water, two days following the test also showed surprisingly little iodine. The two-day delay interval reduced the amount of direct-yield iodine by radioactive decay; however, if large amounts of iodine had been released, it would have been readily detectable. On the date of analysis, the environmental tank water (≈9500 gal) contained 3.15×10^{-5} μc/ml or a total of 1.2×10^{-3} curies of I-131, compared to the total available quantity of 0.92 curie calculated by the CURIE code.

Similarly, the iodine-133 data showed a small amount (4.4×10^{-3} curies) of I-133 in the water, compared to the calculated quantity of 4.3 curies for the corresponding time.

The evidence from thest two isotopes of iodine indicates that the release of iodine into the water was quite low.

1.4 Iodine Retained in the Fuel

Radiochemical analysis of the twelve samples of fuel taken from four different fuel pins showed an average concentration of 17 μc of I-131 per gram of fuel at this time. This average value gives a total of 0.87 curies of I-131 remaining in the fuel compared with the CURIE code calculated quantity of 1.0 curies. Thus, it appears that roughly 87 percent of the I-131 was retained in the fuel. While this average value does not take into account the variation of neutron flux from sample to sample and the degree of fragmentation of fuel pins, it does serve to show that a major portion of the I-131 remained in the fuel. It can be speculated that other isotopes of iodine behaved in a similar manner.

1.5 Iodine Plate-Out

An additional location for the deposition of iodine was the surface area of the environmental tank and pipings leading from the environmental tank to the liquid waste tanks into which the environmental water was emptied. It is well known that the tellurium precursor of iodine readily plates out on vessel surfaces from an aqueous solution. This along with the fact that iodine was detected evolving from the

environmental tank following its draining, indicates that a portion of the iodine inventory was held on these surfaces. Since no specific sampling for iodine plateout was performed all that can be said is that an undetermined portion of the iodine inventory was deposited on various surfaces in the system.

1.6 Iodine Balance Summary

Although a complete accounting of the total iodine inventory was not realized, the lack of iodine in the cloud and the low concentration in the environmental tank water indicate that the majority of the iodine remained in the fuel. The radiochemical analysis of the fuel, at a somewhat later date, confirms this conclusion, indicating an iodine retention on the order of 90 percent, with the balance being plated-out on tank piping surfaces.

2. Fraction of Noble Gas Released to Environment

It is not possible to perform a calculation on the quantity of radioactive gases released from a full scale reactor destructive test without necessarily making a number of assumptions. It is however possible, in most cases, to select a set of assumptions that can reasonably be expected to give an upper limit to the quantity released and this mode of approach has been used in the following section. Three methods have been used to determine the fraction of noble gases released during the destructive test.

2.1 Diffusion Calculations Using Kr-91, Kr-92, and Xe-139 Decay Chains

An estimate of the fraction of the noble gas fission products released to the atmosphere was made using the data from the quantity of gas daughters collected by high-volume air samplers. First a release model which corresponded to the observed data was postulated. This model was then combined with a Sutton type diffusion equation to determine a source release term from the reactor.

Since only daughters from short lived noble gas fission products were observed on high-volume air sampler filters, it was concluded that only noble gases were released to the cloud. Traces from recording remote area monitors, Figure 8, indicate that the cloud was in the form of a single "puff" type release. Beta film dosimeters data from the radiological tower, Figure 9, indicate that the radioactive portion of the cloud was between 9 and 13 meters above the ground at the tower location.

Isotopic ratios of Sr-92 to Sr-91 indicate that the release was not an instantaneous one concurrent with the time of the excursion but rather one that was delayed several seconds. The observed ratio was less than would have been obtained by an instantaneous release. In order to account for the observed ratio the noble gases were assumed to have been held up for 3 seconds in the column of water expelled during the excursion. It was further assumed that all particulate daughters formed during this time remained in the environmental tank water. A

hold-up time of 3 seconds predicts a ratio of Sr-92 to Sr-91 in good agreement with the observed data. It also coincides favorably with the time interval during which the ejected column of water remained above the environmental tank following the excursion, Figures 10 and 11.

The 3-second-delay model was adopted on the above basis, although the lack of agreement between the predicted and observed ratio of Ba-139 to Sr-91 indicated additional uncertainties in the model or in the inventory calculations performed with the CURIE code.

The postulated release model was then combined with Suttons diffusion equation and the high volume air sampler data in order to calculate the quantity of noble gases released to the cloud. To do this, the cloud was assumed to follow the basic meteorological diffusion equation for a ground level release.

$$X_p = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z}$$

where

X_p is the peak time-integrated doncentration at downwind distances obtained by dividing the activity collected on each filter by the flow rate of the sampler

Q is the source term, curies released

$\bar{u}$ is the mean wind speed, meters per second

σ_y is the lateral cloud spread, meters

σ_z is the vertical cloud spread, meters.

An average value of $0.20\ x^{0.85}$ was determined from the lateral cloud spread, σ_y, as a function of distance. This value compares very well with other NRTS measurements made by the U. S. Weather Bureau for 30-minute traces released under similar meteorological conditions. In contrast to the measured σ_y parameter, essentially no measurements of the vertical cloud spread, σ_z, were obtained. Therefore, an estimate of the σ_z parameter was necessarily used in determining the source term, Q.

NRTS experience indicates that for slightly unstable conditions observed during the test the distance dependency of σ_z will not exceed that of σ_y and that normally it would be on the order of 2/3 σ_y. Using the maximum condition of $\sigma_z = \sigma_y$ and the measured value of $\sigma_y = 0.20\ x^{0.85}$ yields a straight line curve from equation one with a slope of -1.7, whose value at a distance of one meter is numerically equal to the curies released.

Figure 12, shows the peak time integrated concentration X_p obtained from air sampler measurements made on each arc. The height of the terrain as a function of distance from the reactor is also shown. The

dark straight line curve drawn through the last three measured points is a theoretical line with a slope of -1.7 calculated from the diffusion equation.

The theoretical line was drawn through the last three points of the experimental data on the basis of the postulated release of the radioactive cloud at a height of eleven meters.

The cloud was then assumed to remain at a constant level above the ground out to about 1600 meters where terrain takes a sharp rise of about 10 meters. At this point it is assumed the terrain intersected the cloud trajectory and measured values of X_p from the three remaining arcs represent true ground level diffusion. The maximum value of Q is then obtained by drawing a curve with this slope through the points from the last three arcs on the grid which represent the highest values of X_p with respect to distance.

A curve with a slope of -1.7 drawn through X_p from the last three arcs gives an extrapolated source release term of $Q = 1.0 \times 10^6$ microcuries.

The source term calculated from the extrapolated curves is the microcurie amounts of Sr-91 at the time of 2.28 hours after the test assuming a puff release. According to the CURIE code calculations, the total Sr-91 inventory available from its krypton parent at this time was 25.6 curies. Comparing the largest or upper limit extrapolated source term with this inventory determines a release fraction for the Kr-91 decay chain of about 4 percent. By similar comparisons, the upper limit release fraction for the Xe-139 chain was about 3.0 percent and for the Kr-92 chain about 3.0 percent. One can assume comparable release fractions for other noble gases. However, the fission yields and decay modes of these other noble gases were such that their daughters were not detected by gamma spectroscopy of the air sampler filters.

2.2 Cloud Volume Calculation - Xe-138 Decay Chain

The quantity of noble gas released can be calculated from a knowledge of the cloud volume and the concentration of the noble gas in that volume.

The concentration of the noble gas (Xe-138) detected by a fission gas detector on the 25 meter arc was calculated to be 1.7×10^{-4} μc/cc. This corresponds to the collection of 1.4 μc of Xe-138 in the detector balloon during the 10 second cloud passage time and a sampling rate of 830 cc/sec. Air particulate samples showed that the maximum concentration recorded from the cloud was nearly 4 times that detected at position A-3. Accordingly the cloud concentration of Xe-138 was increased by a factor of 4 to obtain an upper limit estimate of 6.8×10^{-4} μc/cc.

The cloud volume was estimated as follows:

(a) The height of the cloud at the 25 meter arc was determined by visual inspection of motion pictures and by beta film dosimeter

readings on the tower. Both of these determinations indicate that the top of the cloud was approximately 12 meters.

(b) The length of the cloud was also calculated from motion picture data which showed that it took 10 seconds for the cloud to pass the 25 meter arc. This time combined with a wind speed of 25 mph gave a cloud length of 110 meters.

(c) The cloud width was bracketed with air sampler data. Radioactive particulates were detected on station A-3 and A-4 of the 25 meter arc and were not detected on A-2 and A-5. Since these stations are located approximately 13 meters apart, it was estimated that the cloud width was on the order of 30 meters. Using these bracketing figures which should over estimate the cloud gives a volume of 4.13 x 10^7 cubic meters.

This volume combined with the concentration of Xe-138 of 6.8 x 10^{-4} μc/cc gives a total release of 27.6 curies or roughly 4% of the 630 curies produced in the excursion.

2.3 Fuel Analysis Xe-137 Chain

An indirect approach to the measurement of the release of the noble gases can be made by analyzing the reactor fuel for the quantity of the daughter activity remaining in the fuel. This approach was used on the Xe-137 decay chain by comparing the amount of Cs-137 remaining in the fuel to the amount ideally available from the total chain yield of Cs-137 for the integrated energy release from the fuel. The difference between the calculated value of the available Cs-137 and the measured value gives the number of parent atoms (I-137 and Xe-137) that were released. By combining the fuel analysis with a normalized flux distribution over the core, this comparison technique indicates that an upper limit on the release fraction of the xenon-137 chain was less than 5 percent.

A similar indirect measurement was possible using Kr-85 because its 10.4 year half-life allowed little decay.

One sample of fuel from fuel pin E-147 was analyzed and showed 3.9 x 10^{-3} μc of Kr-85 per gram of fuel. This value, normalized over the core, indicates that 2 x 10^{-4} curies of Kr-85 remained in the fuel, or nearly 80 percent of the CURIE code quantity. It is felt that this quantity is less than the percent retained during the test because of the opportunity for the gas to diffuse from the fuel subsequent to the destructive excursion. The results do, however, indicate that the majority of the Kr-85 remained in the fuel.

2.4 Summary of Noble Fission-Gas Release

Three independent methods were used to calculate the fraction of noble fission gases released during the power burst. Two of these depended upon actual measurement of the cloud and one on analysis of the fission products remaining in the fuel. All indicate a low percentage release. It is felt that the diffusional calculations

using the Kr-91 chain represent the most reliable determination because of the considerably larger number of measurements used to establish the model. On this basis it appears that the percentage release of the noble fission gases should be considered to be on the order of four percent.

The summation of noble gases formed directly by the excursion was calculated by the CURIE code to be 8×10^5 curies, about 10 percent of the total fission product inventory. Four percent of the noble gases corresponds to a release of 32,000 curies.

VII. CONCLUSIONS

The hazards involving the release of toxic and radiological material to the environment in conjunction with the destruction of a SNAP 10A/2 reactor were considerably less than anticipated. The general conclusions which can be drawn from the SNAPTRAN 2/10A-3 destructive test are:

(1) No beryllium was released with the radioactive cloud.

(2) More than 99 percent of the fission products were retained in the environmental water and reactor fuel remains.

(3) Halogens, released from the fuel, were retained by the environmental tank water, with the result that no detectable iodine was released to the radioactive cloud.

(4) The radioactive cloud contained only noble fission gases and their daughters. Calculations indicate that the noble gas release fraction was less than 4 percent of the total noble gas inventory.

(5) There was little dispersion of radioactive debris in the vicinity of the test area. Contamination levels approached background levels three days after the test.

(6) Based on the available data, the most dependable method for determining the fission-product release from the reactor was the diffusion-type calculations based on the spread and dispersion of the radioactive cloud.

The experience gained from this test indicates that (a) better definition of the cloud trajectory and diffusion could be obtained with more closely spaced sampling stations on the monitoring arcs; (b) measurements of the cloud diffusion in the vertical direction were needed for the source term calculations; (c) earlier radiochemical analysis of the fuel would have aided in determining the fraction of the fission product retained in the fuel; (d) continuous pen-type recorders, connected to beta-sensitive, gamma-insensitive detectors, would have provided better definition of the cloud dynamics by responding only when in the immediate vicinity of the cloud.

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In general, it can be concluded that the destructive test was successful in clearly demonstrating that a water immersion accident of a SNAP 10A/2 reactor does not present a serious radiological hazard to the public. It was also successful in demonstrating the conservatism inherent in the analytical procedure for performing safety analysis on this type of reactor, e.g., actual release of less than 4 percent of noble fission gases compared with the 100 percent release normally postulated.

VIII. GENERAL REFERENCES

1. W. E. Kessler, et.al., SNAPTRAN 2/10A-3 Destructive Test Results, IDO-17019, (January, 1965).

2. O. I. Cordes, et.al., Radiological Aspects of SNAPTRAN 2/10A-3 Destructive Test, IDO-17038, (January, 1965).

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