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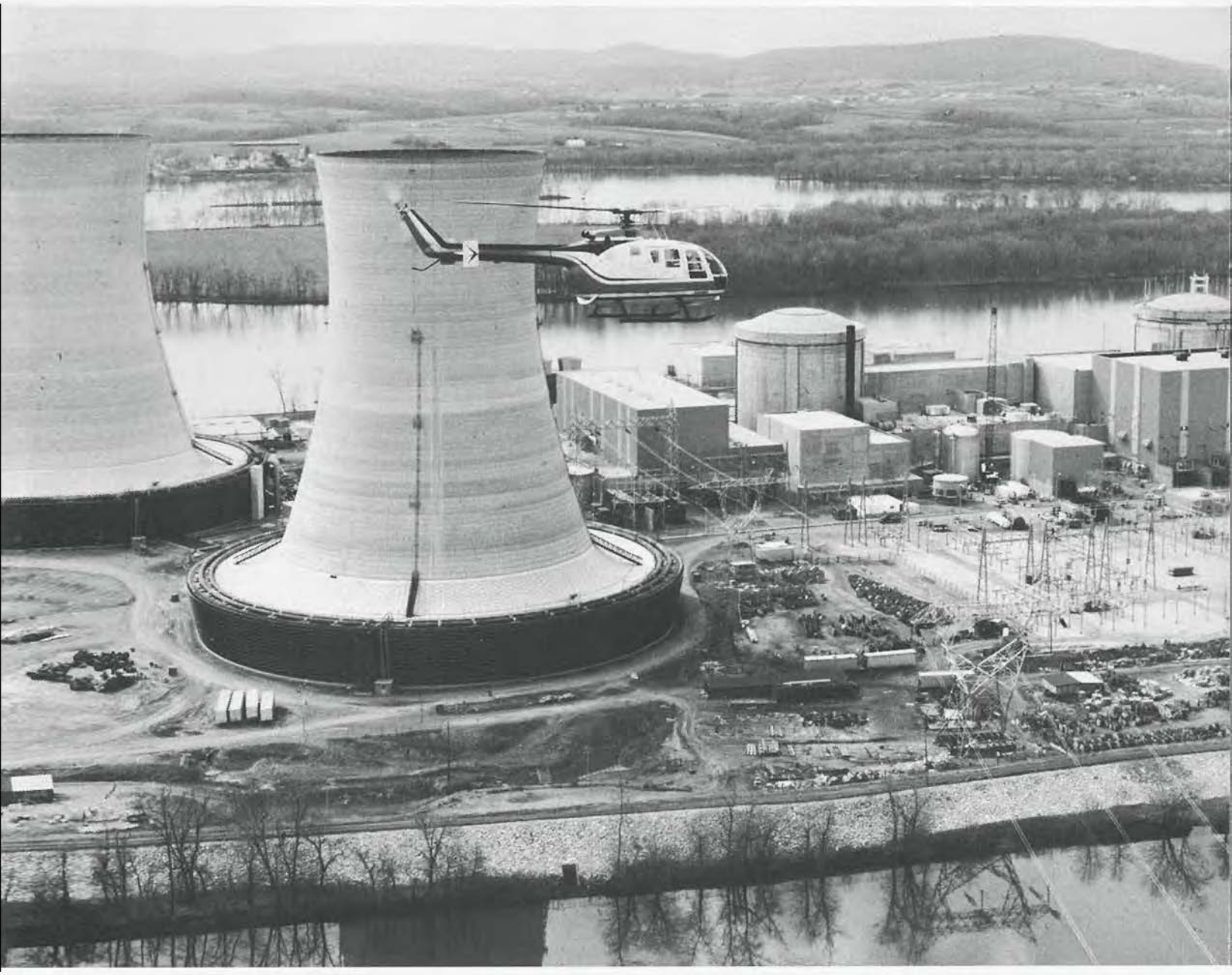
THE
REMOTE SENSING LABORATORY
OPERATED FOR THE U.S.
DEPARTMENT OF ENERGY BY EG&G/EM



AIRBORNE CLOUD TRACKING MEASUREMENTS DURING THE THREE MILE ISLAND NUCLEAR STATION ACCIDENT

MIDDLETOWN, PENNSYLVANIA

DATE OF SURVEY: MARCH - JUNE 1979

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ABSTRACT

The Department of Energy's Aerial Measuring Systems (AMS) flew aerial monitoring missions in response to the Three Mile Island nuclear accident. The first flight was made at 1600 hours EST on 28 March 1979, the first day of the accident. Over 150 flights were made during the period of greatest concern. Measurements included isotope identification, plume direction, and maximum radiation levels inside the plume. The highest exposure rate measured (15 milliroentgen per hour, mR/h) was at 300 feet altitude, 1/4 mile from the plant, at 1030 hours on 30 March 1979. The highest measurement at 1 mile was 4.5 mR/h; this occurred at 1600 hours the same day. The Nuclear Emergency Search Team's (NEST's) communication system and logistic support contributed significantly to the overall DOE coordination of off-site radiation measurements.

The AMS also provided real time measurements of radioactive krypton gas during purging operations in June 1980.

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1.0 INTRODUCTION

The Aerial Measuring Systems (AMS) program,* operated for the U.S. Department of Energy (DOE), has been prepared to respond to reactor accidents since 1958. This response capability has been a vital part of DOE's environmental assessment and accident response program. Radiation accidents such as the Windscale Number One Pile accident in England (1957) identified a need for an aerial radiation measurement capability.[1] The U.S. Atomic Energy Commission developed such a program in 1958.[2,3] This capability represented a state-of-the-art system utilizing the latest solid-state multichannel analyzer and a new lightweight doppler radar which provided more accurate position information for the radiation detected by the aircraft.

Since 1960 this system (developed and operated by EG&G Energy Measurements, Inc.) has performed a large number of experimental and routine large-area radiological surveys and has responded to incidents involving nuclear radiation hazards.[4] For example, in 1968 ARMS located a 330 mCi cobalt-60 source lost from a truck somewhere between Salt Lake City and Kansas City, a distance of 1900 kilometers.[5] In another incident, ARMS located a U.S. Air Force Athena missile containing two 470 mCi cobalt-57 sources which had accidentally strayed 610 km into Mexico.[6]

As a result of the Energy Research and Development Administration (subsequently DOE) role encompassing all energy resource development, an improved and expanded remote sensing capability has been developed.[7] This capability includes a variety of both radiation detection and photo-optical instrumentation compatible with various aerial platforms.

The creation of the Nuclear Emergency Search Team (NEST) in 1974 broadened the aerial search and identification capability. NEST resulted from the aerial survey capability, developed in 1970, to detect and quantify the presence of americium-241 in the environment.[8] In addition, NEST required the development of logistics and communications capabilities which would prove to be of significant value in the on-scene coordination of large, technically complex operations involving large numbers of personnel and specialized equipment.

The combined capabilities of NEST and AMS provided the basis for the successful detection of the radioactive fragments of Cosmos 954, a nuclear-powered Russian satellite which crashed in the Northwest Territories of Canada in 1978.[9]

Between 1958 and 1978 hundreds of background radiation surveys were performed as part of DOE's Operational and Environmental Safety program. The primary purpose of these surveys was to establish background radiation levels with which the effects of continued routine operations or an accident could be compared. In 1976 a background aerial radiological survey was conducted over a 2000-square-kilometer area surrounding the Three Mile Island (TMI) Nuclear Station.[10] In October 1982 a more detailed survey was conducted over a smaller area surrounding the station.[11] The station is located on an island in the Susquehanna River, approximately 25 km downstream from the city of Harrisburg, Pennsylvania.

The mission of AMS is to assess rapidly the radiological situation in the event of a reactor accident or any other radiological emergency. The primary role within this mission is to measure quickly and extensively the surface contamination on the ground and to document both the radiation level and extent of surface deposition. Instrumentation and survey methodology have been developed to this end.

The conditions during the TMI accident required that plume directions and approximate radiation levels be determined. Thus, one of the most important functions of AMS during the TMI accident was to provide plume identification and direction and relative orders of magnitude radiation levels; these results gave the United States Nuclear Regulatory Commission (NRC) guidance for operational decisions. All the sophisticated, state-of-the-art instrumentation developed for accurate low-level surface contamination surveys was not used. This new function required an aerial platform, simple survey meters, improvised procedures, and dedicated crew members.

Continuous command post operations to manage not only plume data but the extensive ground monitoring data of both federal and state efforts were based on AMS/NEST command, control and communications resources.

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* Formerly the Aerial Radiological Measuring System (ARMS) program.

2.0 INITIAL RESPONSE

The AMS, as part of the Interagency Radiological Assistance Plan (IRAP), received its first notification concerning a possible nuclear problem at approximately 0945 EST on Wednesday, 28 March 1979. The Operational and Environmental Safety Division of DOE advised the DOE site representative at Andrews AFB, Washington, D.C. of a problem at an east coast nuclear power station and instructed him to review the status of the AMS assets located at Andrews. A subsequent telephone call alerted AMS personnel in Las Vegas, Nevada, home base for the majority of both the AMS and NEST deployable assets.

A review of the assets at Andrews showed that all required equipment was operational and available for deployment. Included were a helicopter with sensitive gamma ray detectors and an on-board computer, a mobile van system similarly equipped, a variety of hand-held instruments, and a nucleus of trained personnel to deploy and operate the equipment. A second DOE helicopter was expected to return to Andrews that evening; a fixed-wing aircraft was in the midwest being serviced at the factory. The assets available in Las Vegas were similarly reviewed.

At 1100 hours that morning a formal request to deploy to the Capital City Airport, New Cumberland, Pennsylvania was received at the EG&G/EM Andrews AFB office from DOE Headquarters. DOE had just received the request from the NRC under the provisions of the IRAP. The recommended response was to deploy the helicopter system and four members of an advance party: a DOE official, a senior scientist, an electronics technician, and a pilot. The helicopter system, equipped as described, did not have adequate capacity to transport four persons, so airlift support was requested from the 1st Helicopter Squadron of the United States Air Force (USAF) under the terms of an existing DOD-DOE agreement set up to cover such emergencies.

At 1300 hours a USAF helicopter (CH-3) with the advance party departed from Andrews AFB and arrived at the Capital City airport at 1345 hours. At 1445 hours the DOE helicopter equipped with the radiation detection system arrived. At approximately the same time a Coast Guard helicopter carrying two DOE radiological assistance teams (RAT) arrived from Brookhaven, New York. The Emergency Operations Center (EOC) at DOE Headquarters was informed of the party's arrival and the NRC was contacted. Simultaneously, the DOE helicopter was refueled and the equipment checked and calibrated in preparation for a data flight. Upon instructions from the NRC, the first data flight was launched at 1600 EST 28 March 1979.

The equipment on board the aircraft allowed a determination of gamma radiation levels, isotopes responsible, plume definition, and the affected area. During the first flight, the high-sensitivity gamma ray detectors were saturated;* qualitative results implied exposure rates in the milliroentgen per hour (mR/h) range. The affected area was downwind from TMI over Middletown and Hummelstown. All results were immediately called into the EOC and to the local headquarters of the NRC at King of Prussia, Pennsylvania.

At 1900 hours the NRC requested an additional flight to redefine the plume. New plume characteristics were defined on this flight; the radiation exposure levels seemed somewhat reduced from those observed earlier.

Later that evening the status was reviewed by those assembled at Capital City and, with the concurrence of the NRC and DOE, additional aerial survey equipment was requested. A second helicopter was called from Andrews AFB. Although not equipped with sensitive radiation detectors, this twin-engine helicopter had greater capability for carrying both personnel and equipment and was equipped with additional navigation instruments, which would prove valuable in the inclement weather. The exposure levels in the mR/h range permitted the use of less sensitive, hand-held equipment. (The large airborne arrays are normally used to measure background radiation levels of 0.05 to 0.15 mR/h. They contain sodium iodide [NaI] crystal detectors.) Included were: exposure level meters sensitive to both beta and gamma radiation, a portable spectrum analyzer for isotopic identification, and an air sampler provided by the team from Brookhaven National Laboratory of New York. The mobile search van, equipped with sensitive radiation detection equipment, was also deployed; it was later instrumented with a high-purity germanium (Ge) detector for high-resolution gamma ray spectroscopy. Additional hand-held equipment,

*Saturation levels occurred above approximately 100 microroentgen per hour (μR/h).

including personnel dosimeters, logistics support equipment, and personnel sufficient for around-the-clock coverage for several days were all called from AMS and NEST resources. The REDAC (Radiation and Environmental Data Analyzer and Computer) mobile van was also brought from Andrews AFB.[12]

Simultaneously, in anticipation of a protracted operation, additional resources from Las Vegas were called upon. In addition to manpower, AMS equipment for documentary photography, aerial infrared spectroscopy and imagery, and health physics, plus communications and logistic equipment from NEST resources, were deployed.

3.0 AERIAL OPERATIONS

All aerial measurement activities were based at the Capital City Airport, New Cumberland, Pennsylvania. Personnel were located at the DOE Command Post in the "Commonwealth of Pennsylvania" hangar facility.

3.1 Flight Schedules

Initial flights were flown at the request of the NRC. Results of each flight were immediately reported to both the NRC and the State of Pennsylvania Bureau of Radiological Health. As the magnitude of the problem became apparent a regular flight schedule was established at approximately three-hour intervals around the clock. This schedule was strictly adhered to except when adverse weather conditions precluded safe helicopter operations. To support this 24-hour-per-day operation, supplementary aircraft and personnel were supplied by the 1st Helicopter Squadron based at Andrews AFB in Washington, D.C. In addition to the scheduled eight flights per day, special flights were flown upon request.

After approximately one week of continuous operations the flight schedule was again adjusted to provide scheduled flights from 0600 through 2100 hours each day, supplemented by standby crews capable of one-hour response.

During the second week the flight schedule was reduced to two flights per day and, toward the end of the operation, to only one flight per day. At all times, however, flight crews were on alert to fly special missions.

3.2 Equipment and Personnel

The equipment and personnel requirements to support the aerial measurement were met with the following:

Equipment

- Helicopters: Messerschmitt-Bolkow-Blohm (MBB) BO-105 (DOE), Hughes H-500C (DOE), and Bell UH1N (USAF).
- Fixed-Wing: Beech King Air A-100 (DOE) and Beech Twin Bonanza E-50 (DOE).
- Computer: REDAC Van (AMS) from Andrews AFB.
- Four Portable Spectrum Analyzers: one with Ge detector, three with NaI(Tl).
- Survey Meters: Assorted, hand-held, with microroentgen-per-hour sensitivity.

Personnel

- Scientists: Five
- Technicians: Three
- Aircraft Mechanic: One
- Pilots: Three EG&G/EM (DOE) and three USAF (plus three additional USAF co-pilots and flight engineers).

3.3 Aircraft Utilization

Minimum safety standards for flight operations were established by mutual agreement between DOE and DOD pilots. Three levels of flight priority were identified: routine, special, and emergency, with respective flight safety parameters. The twin-engine BO-105 (Figure 1) and UH1N were used in poor weather conditions or periods of expected higher readings. The single-engine H-500C with its precision Microwave Ranging System (MRS) and high-sensitivity gamma detection system[11] was flown during good weather conditions and periods of lowest activity.

Of the four DOE-owned aircraft deployed to the scene, during peak periods three were on alert around the clock. Field maintenance and inspections were performed by DOE. During the entire operation, no mission was delayed because of aircraft or other equipment malfunction. Only adverse weather cancelled or delayed aircraft operations.

TWIN BONANZA

H-500

KING AIR A-100

MBB BO-105

U.S. AIR FORCE UH1N

Figure 1. *AERIAL PLATFORMS AVAILABLE FOR EMERGENCY RESPONSE. For the TMI response, the H-500C, BO-105, Twin Bonanza and the King Air A-100 were utilized. In addition, a U.S. Air Force UH1N helicopter was used.*

3.4 Measurements

Basic plume tracking measurements were made by flying a 360° circle at a one-mile radius from the plant to determine plume direction. Nominal flight altitude was 500 feet. A hand-held gamma survey meter was used to define the direction of the plume, if it could be identified.

Aerial radiation monitoring activities included:

- Isotope identification measurements taken in the plume with the portable spectrum analyzers.
- Direct radiation measurements taken with thin-window Geiger-Mueller (G-M) survey instruments to enhance detection of any beta radiation which might be present.
- Special surveys made from helicopter and ground vehicles whenever higher than normal discharges from the TMI station were reported or anticipated.

When maximum radiation levels were encountered, plume direction and peak readings were recorded on flight notes. Measurements were then made as a function of altitude to identify the vertical extent of the plume. The plume was then tracked to five miles, where measurements were repeated. Frequently the plume was tracked to the radial limits of detectability. Spectral measurements were made from the BO-105 and UH1N using the Lawrence Livermore National Laboratory (LLNL) Portable Spectrum Analyzer (PHA) (Figure 2).

3.5 Aircraft Positioning

For most of the measurements, aircraft positioning was determined by two methods: visual map navigation and radar altimeter. The radar altimeter aboard the helicopter measured the time lag for return of a pulsed signal and converted this to aircraft altitude. For these surveys, altitude was accurate to ± 2 m. To correlate measurements with distances from the reactor site, concentric circles at one-mile intervals were drawn on a current map of the area. The pilot and data scientist then estimated the distance from the reactor by visually relating the ground features with the map. A microwave ranging system was available but was not used until much later in the operation.

Figure 2. *PORTABLE SPECTRUM ANALYZER FLOWN IN THE HELICOPTER TO HELP IDENTIFY PHOTOPEAKS OF ISOTOPES IN THE PLUME*

3.6 Reporting

Immediately upon completion of a data flight, the scientist consolidated his flight notes and prepared a short report which was transcribed or telecopied to DOE (EOC), NRC, and the Pennsylvania Bureau of Radiological Health. All flight notes were then made part of a permanent record file which was further summarized and reported at the end of each day.

3.7 Thermal Scanning

Thermal infrared (8-14 μm band) scanning was performed at about 2000 ft altitude over the facility twice, at dusk and predawn. The purpose was to obtain baseline documentation of the thermal characteristics of the area, including the river, in case reactor complications warranted further surveys.

A Daedalus D1260 multispectral scanner was used with a mercury-cadmium-telluride (Hg:Cd:Te) detector for the thermal infrared band. System sensitivity at a signal-to-noise ratio of unity was better than 0.1° Kelvin. The aircraft used was the Twin Bonanza. The data were gathered on 5 April

1979 (post sunset) and on 7 April 1979 (predawn). A description of this capability is included in Appendix A.

3.8 Aerial Photography

An area approximately 25 × 40 miles was photographed using a large format aerial mapping camera in the King Air A-100 aircraft. Separate missions were flown to document an area 10 × 12 miles with a four-camera multispectral system.

The mapping camera was a Wild RC-10 which produced overlapping imagery suitable for stereo viewing or making a mosaic. The imagery from the TMI area was assembled into a mosaic for use as a base for data presentations. Imagery with the mapping cameras was obtained at 4,000-, 10,000- and 20,000-ft altitudes.

Multispectral imagery, which is used for a variety of purposes including vegetation analysis, land use applications and other interpretative uses, was acquired with four Hasselblad EL-70 cameras aligned on a common optical path. The cameras were triggered simultaneously to image an area on the ground in four separate spectral regions. One multispectral photography mission was flown at an altitude of 8,000 ft on April 10.

Five missions were also flown in helicopters to acquire oblique aerial photographs, for situation updates, and subsequent documentation.

4.0 SUPPORTING EFFORTS

EG&G/EM provided various support functions to the DOE Command Post at the Commonwealth of Pennsylvania hangar at the Capital City Airport. DOE operations were under the direction of representatives from Germantown Headquarters, the Nevada Operations Office, the EG&G/EM AMS/NEST team and Radiological Assistance Team leaders. The DOE Command Post also provided logistical support for other federal agencies including the NRC, the Defense Civil Preparedness Agency (DCPA), National Oceanic and Atmospheric Administration (NOAA), and the Environmental Protection Agency (EPA).

4.1 Communications

On 28 March 1979 the advance DOE parties from Brookhaven National Laboratory (BNL) and Andrews AFB arrived at Capital City Airport, New Cumberland, Pennsylvania and met with the manager of the airport. A temporary Command Post was set up in the manager's office, using his telephone system for communications. On Thursday and Friday, 29 and 30 March, it became increasingly clear that the exact nature and possible consequences of the accident were not fully known. To manage effectively and coordinate the deployment of large numbers of health physics monitors and aerial survey activities in an operation of this magnitude required a dedicated communications and support network. The DOE AMS/NEST team was called to provide this support. The complete communications system,[13] packaged in airline cargo containers, was flown from Las Vegas, Nevada to the Capital City airport. By early Sunday, 1 April, all the DOE radiological assistance teams were radio linked.

The system provided communication links to field teams of scientists, technicians, and monitors, as well as communication between the Command Post and the DOE laboratories for analysis of data. The participants relied heavily on the telephone system, with radio backup via the existing DOE Emergency Radio System (ERS). Coordination with AT&T* provided dedicated lines between the Pennsylvania Bureau of Radiological Health, DOE Washington, and the NRC.

The communications center, packaged in an airline cargo container (Figure 3), provided the controls and interfaces for the landline telephone system (ten lines—tone or dial), the radio telephone (two lines), the HF radios (ERS), the VHF field radio system (up to 100 handi-talkies), the slow scan video transceiver, the commercial television receivers, and the video recorder and printer.

Field units communicated via an automated system of VHF radio repeaters. Each repeater system was a lightweight, self-contained and portable system consisting of a power supply, an antenna, and a microprocessor-controlled scanning receiver and

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*American Telephone and Telegraph Company

Figure 3. *PORTABLE COMMUNICATIONS CENTER USED AT THREE MILE ISLAND*

transmitter. The two repeaters deployed near the TMI site provided complete radio coverage for a radius of approximately 40 miles around the site.

4.2 Command Post Operations

DOE Command Post support personnel were provided to man and maintain the communications system; to coordinate radiation measurement collection; to input, analyze, and report radiological findings; and to provide logistics and mechanical support for the large quantities of specialized equipment (Figure 4).

Figure 4. *DOE AND EG&G/EM PERSONNEL OPERATING THE COMMAND POST IN THE COMMONWEALTH OF PENNSYLVANIA HANGAR*

To support the communications network, which was used by the entire DOE task force around-the-clock, communicators were on duty to coordinate message traffic, service the portable repeaters, and maintain handi-talkies and pager units.

A team of health physicists worked continually at assimilating all incoming radiological data and presenting the results in a timely and understandable fashion to the State of Pennsylvania and the NRC. A graphic overlay display system consisting of aerial photographs, geological maps, population distributions, meteorological conditions, and radiological health data was used to present daily status reports (Figures 5 and 6). These results were also transmitted to the DOE and NRC Headquarters by the most expeditious system available: hand courier, telecopier, or slow scan television transmission.

Clerical personnel provided 16-hour-per-day support. In addition to the routine paperwork and office support expected during such an operation, a final field report was prepared while key personnel were still on scene.

4.3 Documentary Photography

DOE participation in the operation was photographically documented from the arrival of the first DOE and EG&G/EM personnel on 28 March. Approximately 1600 photographs were taken of all phases of the operation, including the operations of all agencies supporting the DOE.

Photographic support was provided to management personnel and the various agencies located at the airport command post. Data presentations, such as current radiation information, were copied and reproduced using an 8 × 10 color camera. These copies were quickly distributed to scientific personnel and various government entities.

Additional technical photographic capability was available at the Capital City command post for use in recording possible emergency situations. A variety of long focal-length lenses and other specialized equipment were part of this capability.

Complete proof sets of all imagery were provided to the President's Commission on the Accident at Three Mile Island, DOE Headquarters, and NRC Headquarters. The imagery has appeared in most official reports concerning the TMI accident.

5.0 AERIAL DATA

There were three basic parameters measured by the AMS/NEST helicopter during the course of a data flight: exposure rate levels, isotopic identification,

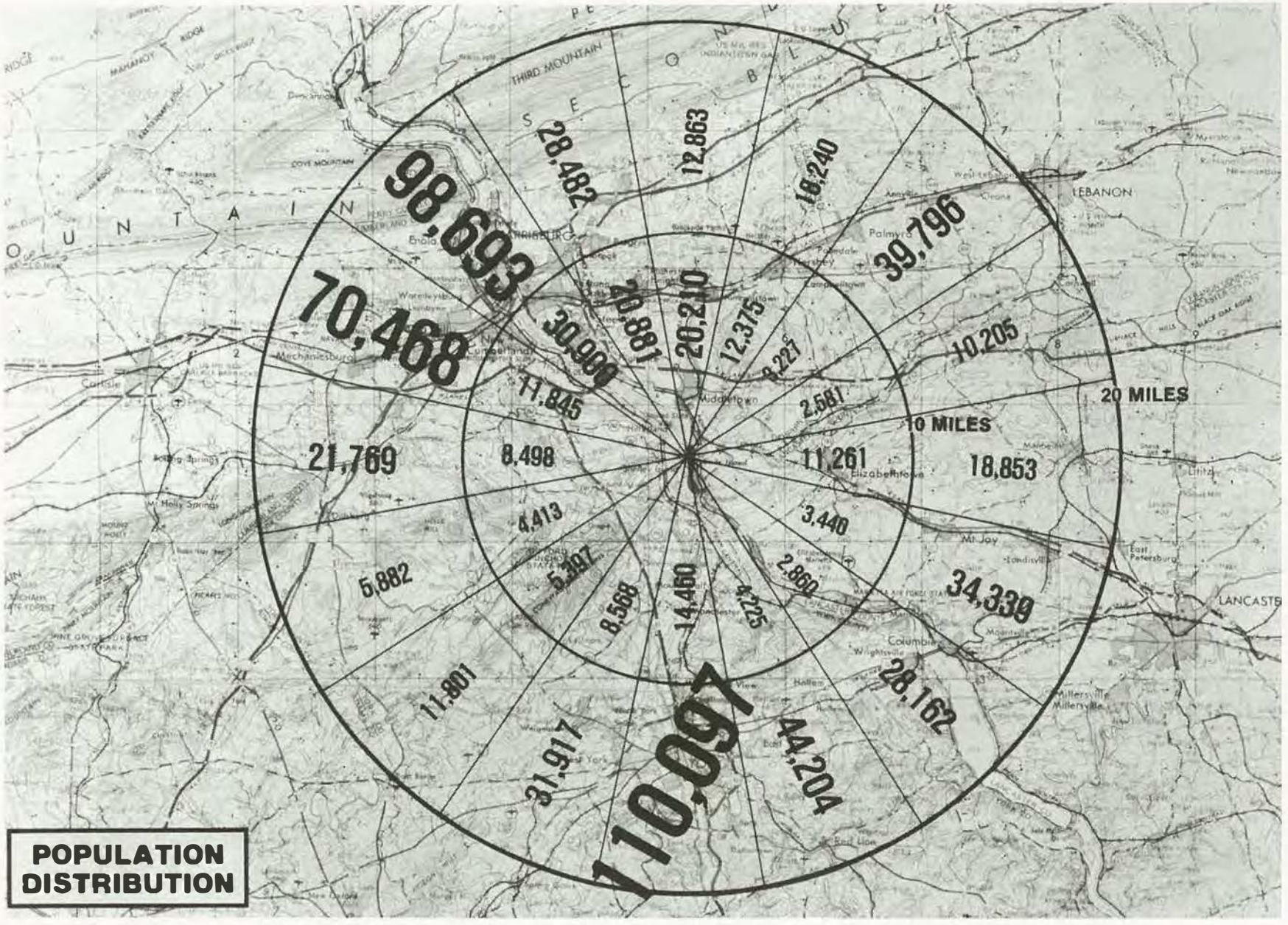


Figure 5. *POPULATION DISTRIBUTION SURROUNDING THE THREE MILE ISLAND CRIPPLED REACTOR. This is an example of a graphic overlay display system developed during the accident to display the environmental monitoring being conducted.*

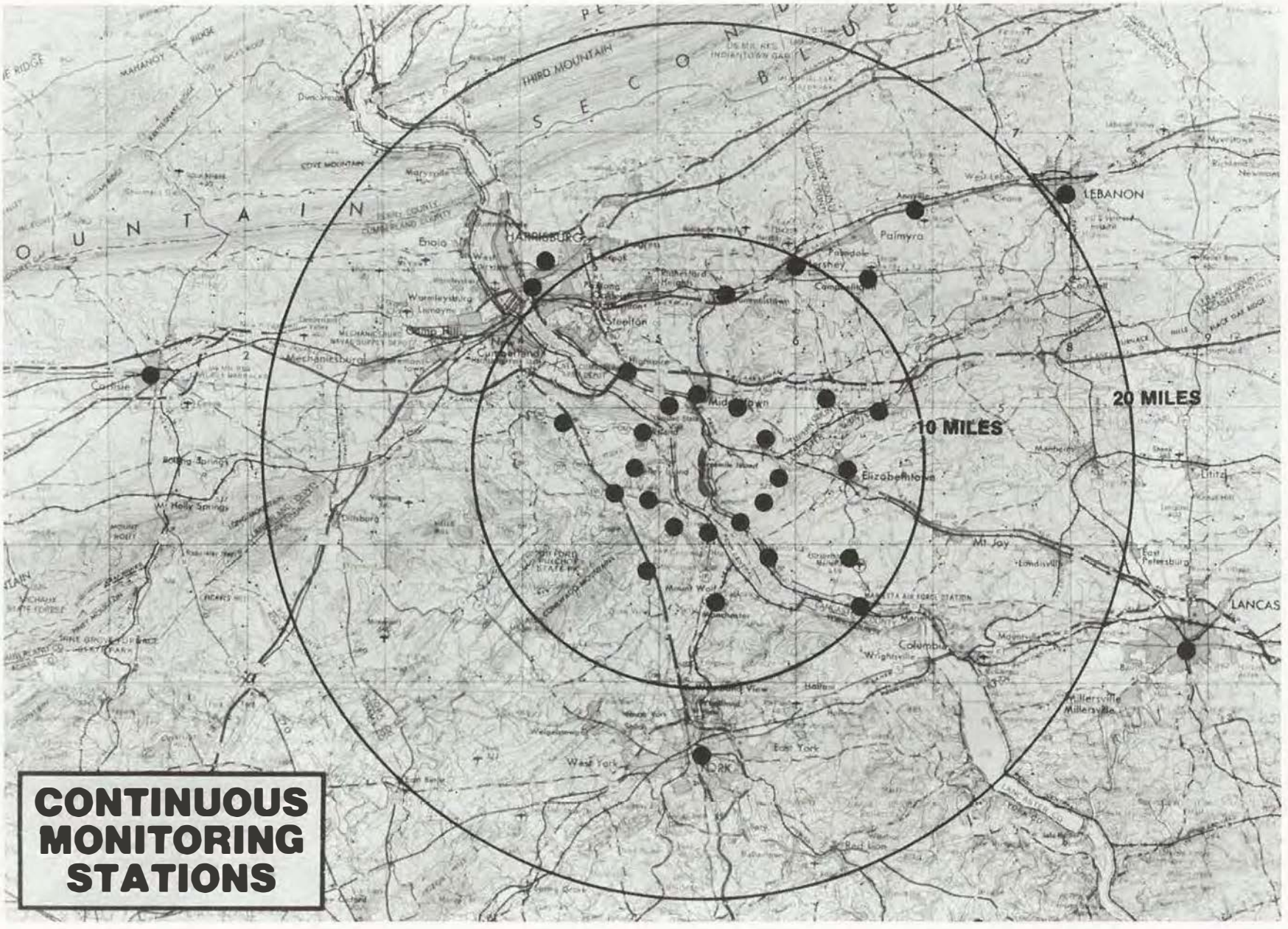


Figure 6. *CONTINUOUS AIR MONITORING STATIONS SURROUNDING THE THREE MILE ISLAND CRIPPLED REACTOR*

and the physical characteristics of the plume. The primary data consisted of the following: scientific flight notes, gamma ray spectra, computer tapes, air samples, and survey meter readings.

5.1 Flight Notes

The primary flight notes were handwritten during the flights. They normally contained relevant meteorological data, time and date, and exposure rate as a function of aircraft position. Upon completion of a flight, this information was immediately typed and proofread by the scientist. In most cases the scientist initialed the typed copy indicating correct transcription. A complete copy of these flight notes is contained in Appendix B. The original notes are available in the archives.

5.2 Gamma Ray Spectra

Depending upon the aerial system used, the gamma ray spectra were recorded in one of two ways. If the large detector system (H-500C helicopter) was used, all spectral data were recorded on magnetic tape and analyzed after the flight. Permanent records of these flight data are preserved on tape. The BO-105 system was used much more often; these data were temporarily stored in the memory of the portable spectrum analyzer. During each flight the scientist would make a technical judgment as to spectral identification, erase these data, and begin collecting another spectrum. The limited memory capability of this portable system precluded the permanent storage of data. The scientific evaluation of these spectra is contained in the flight notes.

5.3 Computer Tapes

If the H-500C system was used with its on-board computer system, the data were stored on magnetic tape and available for complete analysis by the deployed mobile computer system. The data collected by this system are sparse for several reasons: (1) during the first days of the operation, the detector system, even operated at minimum sensitivity, was saturated when operated near the plume; (2) the small space in the H-500C precluded the use of peripheral equipment such as air samplers and cameras; and (3) the setup of the Microwave Ranging System (MRS) for precision navigation was a time-consuming process not carried out until several days into the operation. The data collected by the H-500C were analyzed and the spectral results presented in Section 6.0.

5.4 Air Samples

The AMS/NEST helicopter systems did not include air samplers. However, the scientific team from BNL had brought with them two customized air samplers that were easily installed and operated in the BO-105. The cartridges for collecting the data were limited in number; therefore, air samples were taken on only those flights deemed appropriate by BNL personnel, based on their knowledge of TMI-2 status. After a flight, cartridges or filters were turned over to BNL personnel (or, later in the operation, to EPA personnel) for analysis.

5.5 Survey Meter Readings

From 29 March 1979 to the end of the operation, survey meter readings were made during all helicopter flights. The exposure rate measurements were made with either of two instruments: a gamma scintillation ratemeter or beta/gamma Geiger counter (Figure 7). These instruments were selected because of their immediate availability and the apparent reliability of their calibration as derived from field checks made at TMI. After the operation these meters were sent to the National Bureau of Standards (NBS) for reference to primary standards; a copy of the NBS calibration results is contained in Appendix C. Appendix C also contains a description of each instrument.

It must be understood that the purpose of the measurements was to obtain plume direction and relative order of magnitude of radiation levels; these results gave NRC guidance for operational decisions. It was not possible to obtain exact quantitative values.

The Geiger counter was used for readings generally above 0.05 mR/h; the scintillation gamma ratemeter was used for readings 0.05 mR/h and below.

Even though the flights were made by different pilots, scientists, and technicians, the methods of measurement were consistent from flight to flight. The Geiger counter probe was generally held at or near the window or at waist level. The scintillation

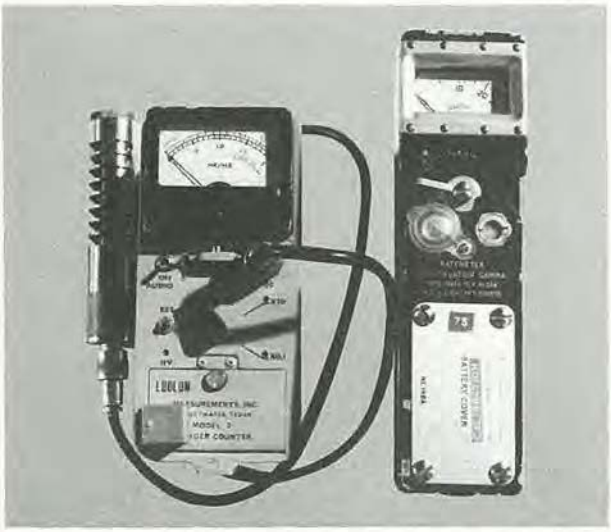


Figure 7. *GAMMA SCINTILLATION RATEMETER AND BETA/GAMMA GEIGER COUNTER USED TO MEASURE EXPOSURE RATES IN THE PLUME DURING THE AERIAL MEASUREMENTS AT THREE MILE ISLAND*

ratemeter was generally placed on the seat, on the LLNL analyzer, or on the floor. For the Geiger counter probe, the beta window was always open, allowing a response to beta radiation and low-energy gamma rays.

The helicopter windows were generally open, which allowed good mixing of inside air with the plume. On two occasions (see Appendix B) measurements were taken both inside and outside the window. No differences were noted.

The maximum reading in the plume was reported in all cases. Readings in the plume were highly variable, usually by factors of 2 to 5. Many times the maximum reading occurred for less than a second and thus was estimated by the swing of the needle on the meter.

6.0 DISCUSSION OF RESULTS

All existing data from the aerial measurements are contained in the flight notes (presented in their entirety in Appendix B) or on magnetic tape. The flight note data are summarized below. Magnetic tape data from the early flights have been analyzed; the results of this analysis are likewise presented.

There were 167 flights made during the period 28 March 1979 through 25 June 1979. These are summarized in Table 1 and again in Figure 8 (for

Table 1. Flight Summary

Date	No. of Flights	Date	No. of Flights	Date	No. of Flights	Date	No. of Flights	Date	No. of Flights
03/28[a]	2	04/15	1	05/03	1	05/21	2	06/08	1
03/29[a]	4	04/16	3	05/04	3	05/22	2	06/09	1
03/30[a]	3	04/17	1	05/05	3	05/23	1	06/10	1
03/31	8	04/18	1	05/06	7	05/24	1	06/11	1
04/01	9	04/19	1	05/07	1	05/25	1	06/12	1
04/02	2	04/20	4	05/08	1	05/26	1	06/13	1
04/03	5	04/21	2	05/09	1	05/27	0[b]	06/14	0[b]
04/04[a]	7	04/22	0[b]	05/10	2	05/28	1	06/15	1
04/05	7	04/23	1	05/11	1	05/29	1	06/16	1
04/06	3	04/24	3	05/12	1	05/30	1	06/17	1
04/07	4	04/25	1	05/13	1	05/31	1	06/18	1
04/08	3	04/26	1	05/14	1	06/01	1	06/19	1
04/09	2	04/27	3	05/15	1	06/02	1	06/20	1
04/10	2	04/28	2	05/16	2	06/03	0[b]	06/21	1
04/11	2	04/29	1	05/17	1	06/04	1	06/22	1
04/12	2	04/30	1	05/18	1	06/05	2	06/23	1
04/13	3	05/01	3	05/19	1	06/06	1	06/24	1
04/14	2	05/02	1	05/20	2	06/07	1	06/25	1

[a] Magnetic tapes containing the aerial radiological data from these flights are in the archives.
[b] Adverse weather (no flight).

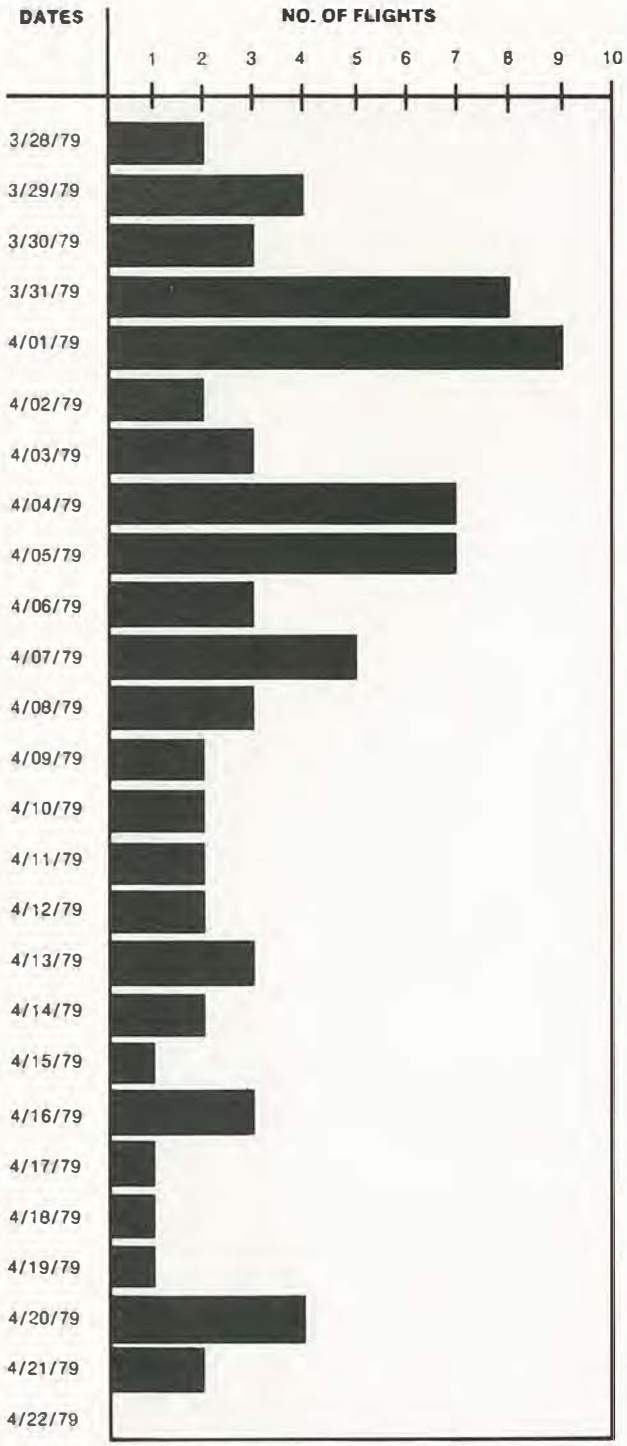


Figure 8. *NUMBER OF PLUME HELICOPTER FLIGHTS DURING THE FIRST TWO WEEKS FOLLOWING THE TMI ACCIDENT*

the first two weeks). Flights continued through 6 July; results from all flights after 4 May were negative. Only those flights which have accompanying flight notes are tallied.

The exposure rate levels were extracted from the flight notes and are presented in Appendix D. Some of these values are also shown in Figure 9. The highest exposure rates observed occurred at 1030 hours on 30 March 1979 at 300 feet altitude and 1/4 mile from the plant. The uncorrected value measured was 30 mR/h. The highest uncorrected value measured at 1 mile was 9 mR/h; this occurred at 1600 hours the same day.

The corrections made on the data summarized in Appendix D are based upon the calibration results provided by the National Bureau of Standards (see Appendix C). The values read from the instruments have been divided by a factor of 2. An examination of the calibration data reveals that the survey meters over-responded to low-energy gamma radiation. The dominant gamma ray energies during the first few days were at 233 keV and 250 keV, due to ^{133m}Xe and ^{135}Xe, respectively. Later, the dominant energy was 80 keV from ^{133}Xe. For the scintillation detector, the meter over-responded by a factor of 3 to 7. For the G-M detector, the instrument over-responded by a factor of 1.2 to 5.5 with the probe window open and a factor of 1.0 to 3.2 with the probe window closed. Choosing a separate correction factor for each instrument, each scale used, and each level measured did not seem justified because of many other uncertainties. Therefore, a factor of 2 was chosen as a single correction factor.

There were no positive readings attributable to TMI operations after 4 May 1979. On certain days, readings as great as twice normal background were obtained, but spectral analysis attributed the increase to airborne radon daughters. Radon is a naturally occurring radioactive gas whose terrestrial releases are meteorologically dependent. Variations of a factor of two or three are not uncommon.

The first day of the TMI incident the H-500C system was used on the periphery of the plume. Detailed analysis of spectral data recorded during this day revealed that in addition to releases of xenon, airborne krypton-88 and its daughter, rubidium-88, were observed. The presence of krypton was of some significance in the modeling of the early stages of the accident. Further analysis demonstrated that the isotopic abundances of the detected releases were consistent with the fission inventory of the TMI reactor. A representative spectrum accumulated approximately 12 hours

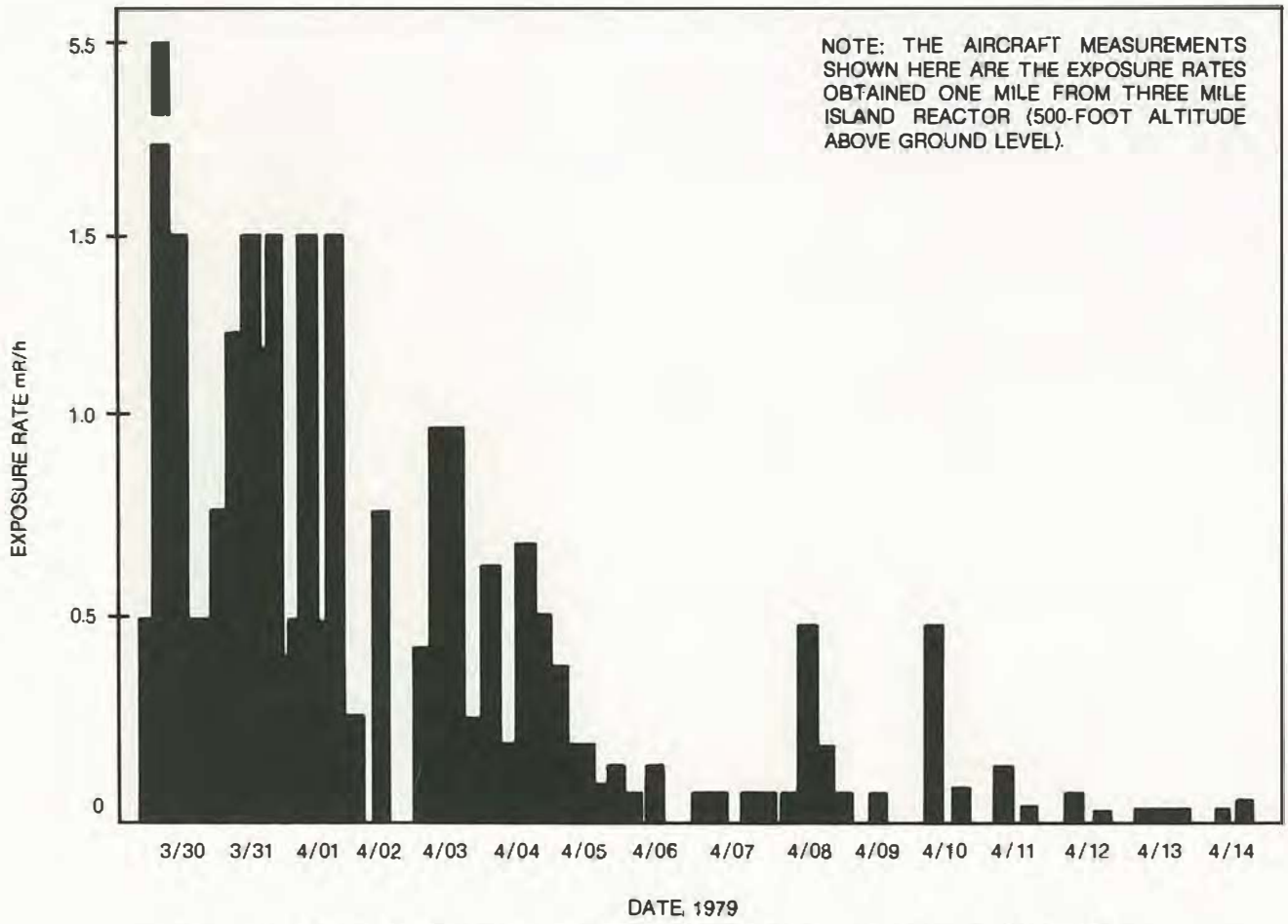
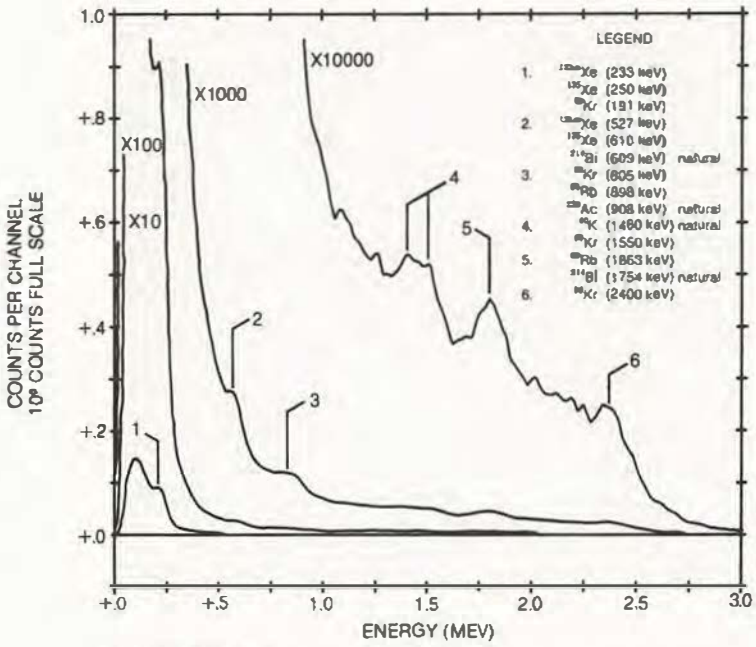


Figure 9. *EXPOSURE RATE VALUES IN THE CENTER OF THE PLUME, ONE MILE FROM SITE*

after the start of the incident is shown in Figure 10. An energy spectrum taken the next day is shown in Figure 11. Examination of the latter spectrum indicates the absence of the shorter-lived isotopes (^{88}Kr and ^{88}Rb).

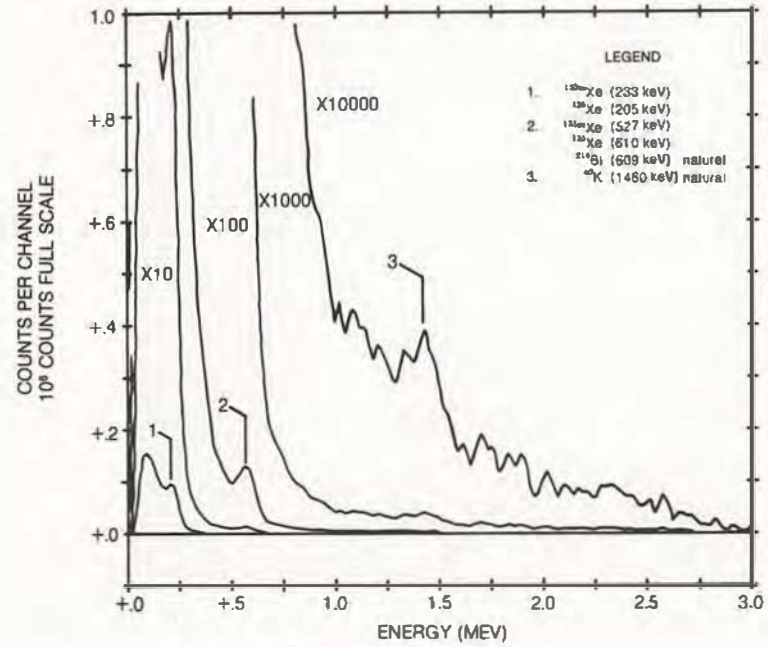
In some instances, increases in exposure rates as a function of distance from the plant were observed. This was primarily caused by time-dependent source releases, and variation in meteorological parameters and topography. These results are further discussed in Appendix E.

For completeness, this report also includes aerial measurements taken during the purging of radioactive krypton gas on 25 and 26 June 1980, 15 months after the accident. These results are given and discussed in Appendix F.



SPECTRUM NO. 1
DATE 3/28/79-1
LIVE TIME (MIN) +.428
INTEGRATED CT. +.2735122E+07
TYPE REC 311-324
AIRCRAFT H-500

Figure 10. *REPRESENTATIVE SPECTRUM TAKEN FROM AIRCRAFT AT TMI ON 28 MARCH 1979.*



SPECTRUM NO. 2
DATE 3/29/79-1
LIVE TIME (MIN) +.747
INTEGRATED CT. +.2484370E+07
TYPE REC 188-207
ALTITUDE AIRCRAFT H-500

Figure 11. *REPRESENTATIVE SPECTRUM TAKEN FROM AIRCRAFT AT TMI ON 29 MARCH 1979.*

APPENDIX A

THERMAL SCANNING AND MULTISPECTRAL REMOTE SENSING CAPABILITY

The remote sensing capabilities of DOE's Remote Sensing Laboratory are incorporated within the Aerial Measuring Systems (AMS) at EG&G/EM, Las Vegas, Nevada. The electro-optical data acquisition capabilities were created in 1977 with the acquisition of a Daedalus multispectral scanner as the principal data collection instrument. The acquisition of a multispectral scanner complemented the aerial photographic and nuclear remote sensing capability already existing within EG&G/EM.

For thermal scanning and multispectral surveys, two main instruments are utilized by the AMS. These are a Daedalus Enterprises, Inc. multispectral scanner (MSS) and an Inframetrics, Inc. thermal infrared imager.

The multispectral scanner is a Daedalus Model DS-1260. The important features of this scanner are:

1. Digital format
2. Two internal blackbody references
3. Excellent spatial resolution
4. Excellent radiometric resolution

The digital format lends itself well to computer processing for efficient and accurate data analysis. This digital format feature is also valuable in removing detector drift by using the blackbody references on a scan-line-by-scan-line basis.

The basic design of the optical system of the scan head consists of a classic Newtonian telescope which has its field-of-view transversed by a 45-degree axeblade scan mirror. The energy collected by the scan mirror is reflected from a parabolic mirror at the opposite end of the scan head. From this position at the rear of the scan head, a dichroic beam splitter lies in the optical path, transmitting a part of the energy and reflecting the remainder. Folding mirrors in both directions from the dichroic reflect the energy to the detectors.

There are two basic configurations that are possible with this multispectral scanner. They are: (1) dual thermal infrared detectors, or (2) a single infrared detector and a ten-channel spectrometer. The dual thermal infrared configuration consists of an indium-antimonide (In:Sb) detector, which is sensitive from 3.5 to 5.5 micrometers, and a mercury:cadmium:telluride (MCT or Hg:Cd:Te) detector, which is sensitive from 8.5 to 13.5 micrometers. Commonly, a 4.5 micrometer cut-on filter is used with the In:Sb. An 8.5 micrometer cut-on filter provides the cut-on for the Hg:Cd:Te detector, while detector sensitivity roll-off limits the longer wavelength sensitivity. Both thermal infrared detectors are liquid nitrogen cooled. The second configuration consists of an Hg:Cd:Te detector (8.5 to 13.5 micrometers) and a spectrometer which is sensitive in ten channels ranging from 0.38 to 1.1 micrometers. Table A-1 lists some of the more significant specifications for the Daedalus DS-1260 multispectral scanner, and Table A-2 lists the wavelength bands recorded by the scanner.

Table A-1. Daedalus DS-1260 Multispectral Scanner Specifications

Item	Description
Number of channels	12
Operating wavelengths	0.35 - 13.5 micrometers
Scan Rate	12.5, 25, 50, 100 scans/second (selectable)
Instantaneous field-of-view	2.5 milliradians
Total field-of-view	85.92 degrees
Temperature resolution	0.1 Celsius
Roll correction	±15 degrees
Reference sources	Infrared: two controllable thermal blackbodies
Video words/scan line	716
Digitizer gains	0.5, 1, 2, 4, 8 (selectable)

Table A-2. Recorded Wavelength Bands		
Channel[1]	Wavelength Band (micrometers)	Color/Spectrum
1	0.38 - 0.42	Near ultraviolet
2	0.42 - 0.45	Blue
3	0.45 - 0.50	Blue
4	0.50 - 0.55	Green
5	0.55 - 0.60	Green
6	0.60 - 0.65	Red
7	0.65 - 0.70	Red
8	0.70 - 0.79	Near infrared
9	0.80 - 0.89	Near infrared
10	0.92 - 1.10	Near infrared
11	8.50 - 13.50	Thermal infrared
12	3.50 - 5.50	Thermal infrared

[1] Channels 1 through 10 are housed in a single silicon array which can be operated simultaneously with Channel 11 (8.50 to 13.50 micrometers) or Channel 11 and Channel 12 (3.50 to 5.50 micrometers) can be operated simultaneously.

The second main data acquisition instrument is an Inframetrics Model 210 dual thermal infrared imager. The imager is different from a line scanner in that the imager has a complete frame in the field-of-view at all times but at a relatively slow refresh rate of 30 Hz.

The collecting optics of the infrared imager consist of a germanium lens and two oscillating mirrors. The germanium lens permits radiation from about two to twenty micrometers to pass onto two mirrors. The two oscillating mirrors are essentially framing mirrors to produce TV compatible 60-Hz rate images. One mirror frames horizontally and the second vertically; each mirror operates so that a new frame is imaged every 30 Hz. The energy collected by the framing mirrors is then directed to a combination dichroic/folding mirror which transmits the 8 to 12 micron energy and reflects the 3 to 5 micrometer energy. The optical path of the 8 to 12 micrometer energy is in line with a folding mirror which reflects the energy onto a side-looking Hg:Cd:Te detector. The energy from the 3 to 5 micrometer channel is also focused on an Hg:Cd:Te detector. Both detectors are cooled by liquid nitrogen. Table A-3 lists important parameters for the Inframetrics Model 210 dual thermal infrared imager.

An important consideration for any type of remote sensing survey is navigation. The navigation system should be: (1) reliable, (2) repeatable, and (3) accurate. The Del Norte microwave ranging system (MRS) currently in use by EG&G/EM contains all three features. This system has been used for aerial radiological surveys for several years and is now a standard navigation aid for multispectral scanner missions. The system is configured with two ground-based remote transponders and one master transponder located on board the aircraft. Software has been written by EG&G/EM for a Hewlett Packard 9825A calculator which does the computations for the MRS. The master transponder on board the aircraft interrogates the remote transponders and receives and displays distances on a distance measuring unit which interfaces with the Hewlett Packard calculator. Position is determined by triangulation and is displayed to the pilot on a meter which indicates deviation of the flight line from the specified path. All flight parameters such as flight line length and intervals between flight lines can be programmed before the mission or changed in flight.

Table A-3. Inframetrics Model 210 Thermal Imager Specifications	
Item	**Description**
Detectors	Mercury:Cadmium:Telluride (2)
Wavelength channels	Channel 1, 3.0 to 5.0 micrometers Channel 2, 8.5 to 12.5 micrometers
Temperature measurement range	−20 C to 200 C (extendable to 2000 C)
Temperature resolution	0.2 C, 64 levels
Temperature gain settings	10, 20, 50, 100, 200 C
Isotherm capability	0 C to 200 C, three scales
Resolvable elements/line	75 in Channel 1; 150 in Channel 2
Resolvable lines/frame	60 in Chanel 1; 120 in Channel 2
Video output format	525 line raster
Frame rate	30 Hz with 2:1 interlace
Total field-of-view	14 × 18 degrees with 4:1 zoom

APPENDIX B
FLIGHT NOTES

FLIGHT 3/28/79-1F **SHIPMAN/WATSON** **TIME: 1600-1700**

East edge of the plume was at Hummelstown, west edge at Rutherford Heights. Levels were about 0.2 milliroentgen per hour at seven miles north of plant. 0.1 milliroentgen per hour at sixteen miles north. Plume extended at least as far as the ridge to the north of Harrisburg. Flown at 150 to 1000 feet. No change in count rate. (No survey meter readings were taken.)

FLIGHT 3/28/79-2F **SHIPMAN/WATSON** **TIME: 1900-2000**

East edge of the plume was at Rutherford Heights. West edge was at Camp Hill. Levels were slightly lower. Top of plume was at about 3000 feet. (No survey meter readings were taken.)

FLIGHT 3/29/79-1F **SHIPMAN/WATSON** **TIME: 1000-1100**

West edge of the plume was at Mechanicsburg. East edge was at Hershey with the maximum at a point about two miles west of the river. The top was at about 3200 feet, the maximum at 2100 feet and the bottom at 500 feet.

FLIGHT 3/29/79-2F **SHIPMAN/WATSON** **TIME: 1600-1700**

The east edge of the plume was at Hummelstown, the west edge at Mechanicsburg. At ten miles, the maximum was about 0.2 milliroentgen per hour. Near Hummelstown, the top of the plume was at 1200 feet, the maximum at 1000 feet, and the bottom at 800 feet. The plume/cloud to the north of the plant appeared to be dissipating and a new plume was forming to the south. At one-half mile south at 500 feet, the highest level was 0.5 milliroentgen per hour. At the site boundary to the south at 500 feet, the levels were 10 milliroentgens per hour.

FLIGHT 3/29/79-3F **SHIPMAN/TIPTON/EICHER** **TIME: 1900-2000**

Circled plant at a distance of eight miles. Saw no plume; only residuals of about 0.1 milliroentgen per hour.

FLIGHT 3/29/79-4F **TIPTON/WATSON** **TIME: 2230-2330**

Plume low and close to plant. Top at about 500 feet. Level at one-half mile of about 1/2 milliroentgen. Plume did not extend more than five miles from plant. Wind from 130 degrees at eight knots. Ridge to northwest split plume with some trapped behind ridge and some going up river at very low altitude.

FLIGHT 3/30/79-1F **MAGUIRE/WATSON** **TIME: 1030-1130**

Maximum level of 20-30 milliroentgens at 300 feet altitude and one-quarter mile SW of plant. From one-half mile out plume is SE of plant. At one mile from plant highest levels are in the SW to the NNE. Approximately 0.5-1.0 milliroentgen per hour at SE. Top at one mile approximately 1500' altitude. Did not extend more than five to six miles in SE direction. At one-quarter mile 500' altitude, eight milliroentgens per hour, WSW of plant.

FLIGHT 3/30/79-2F **SHIPMAN/EICHER** **TIME: 1600-1800**

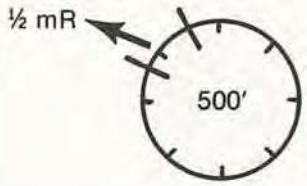
Plume is very narrow. Leaving plant on a bearing of 280 degrees. Hottest point near ground. Top at 1200 feet.

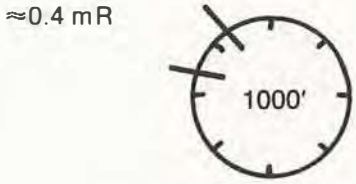
DISTANCE FROM PLANT (Mi)	MILLIROENTGENS AT 300' AGL
1	9
1.5	8
2	8
2.5	8
3	7
3.5	4
5	2

Predominantly up river valley.

FLIGHT 3/30/79 **TIPTON/WATSON** **TIME: 2130-2230**

Flew a circle around the plant at one mile out at 500' altitude and 1000' altitude. Cloud approximately 30-40 degrees wide going to the NW. Maximum reading approximately 1/2 milliroentgen (with scintillation counter).





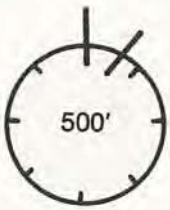
Flew altitude spiral from 1500' to 300' approximately three miles from plant at a heading of 330 degrees. Entered the cloud at approximately 1000', maximum at approximately 500', decreasing down to 300' where had to level off.

Flew a radial at a heading of approximately 330 degrees out from the plant. Seeing levels varying from 0.1 to 0.2 milliroentgen per hour all the way out, eighteen miles from plant until broke off line due to ridge. Radial flown at 500' altitude.

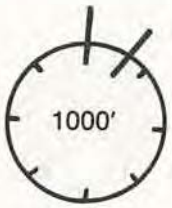
Flew half circle at distance of five miles out from plant. Still approximately 30-40 degrees wide. Altitude 500'.

FLIGHT 3/31/79 **TIPTON/WATSON** **TIME: 0015-0105**

Performed a circle around the plant at one mile out at 500' altitude and 1000' altitude.



≈1 mR/h



less than a few tenths of an mR

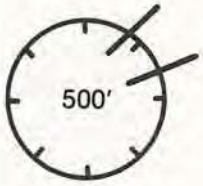
Wind out of 240 degrees

Flew a radial at 500' altitude in a direction of approximately 020 degrees out for eighteen miles before breaking off. Did not run out of the plume. Levels were about 0.1 milliroentgen per hour along the path of the plume. Measured approximately 20 degrees angular spread out at eighteen miles as did at one mile.

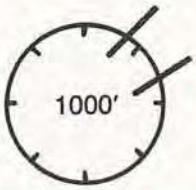
Did an altitude spiral about six miles out from the site in a direction of 020 degrees from 1500' to 300'. Entered the cloud at 800'. Continued to increase all the way down to 300' where had to level out. Maximum reading at 300' was 0.15 milliroentgen per hour.

FLIGHT 3/31/79-2F **MAGUIRE/EICHER** **TIME: 0300-0400**

Flew a circle around the plant at one mile out at 500' altitude and 1000' altitude.



~1.5 mR/h



0.5-0.7 mR/h

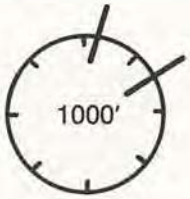
Wind out of 245 degrees (25 knots) at 500' altitude

Flew a radial at 500' altitude in a direction of approximately 060 degrees out for twenty miles. Plume extends past twenty miles. Narrow cone (approximately 5 degrees) at 14 miles had levels of 0.1-0.2 milliroentgen per hour.

Flew altitude spiral at 2.5-3 miles out in a direction of 060 degrees from the plant. At 1100'-1500' altitude—0.02 milliroentgen per hour—700'-1100' altitude 0.03 milliroentgen per hour. Sharp top between 600' and 700'. Levels rise to approximately 1 milliroentgen per hour between 600' and 700' altitude. Stay constant down to 200' altitude.

FLIGHT 3/31/79 **MAGUIRE/EICHER** **TIME: 0600-0715**

~2.5 mR/h
050°



0.5-0.7 mR/h
050°

Ground wind 8 knots at 245 degrees

Flew out along 050 degree radial. Levels dropped from 1 milliroentgen per hour at approximately 1.5 miles out and dropped to 0.1-0.2 milliroentgen per hour at thirteen miles. Levels stayed constant out to thirty miles from the plant. Top of plume is sharp at 600'. 0.1-0.2 milliroentgen per hour levels were present to the ground. Width of plume appeared the same at four miles out and twenty miles out (approximately two miles wide).

All along plume top appeared at 600' with constant levels from 0-500' altitude.

FLIGHT 3/31/79 **SHIPMAN/WATSON** **TIME: 0900-1000**

At one mile and 500' plume was between 030 and 060 with maximum at 045 of 3 milliroentgens per hour. At one mile and 1000' plume was between 030 and 060 with maximum at 045 of 0.5 milliroentgen per hour. At three miles in center of plume, top was at 800 feet and went to ground level. Dose rate nearly constant throughout value of 1 milliroentgen per hour.

At three miles, the plume was from 030-050. Radial away from plant on 045 was 3 milliroentgens per hour out to two miles, 2 milliroentgens at three miles dropped to 1 milliroentgen by ten miles.

Followed plume to Myerstown, about twenty-two miles where the level was about 0.1 milliroentgen per hour.

FLIGHT 3/31/79 **SHIPMAN/WATSON** **TIME: 1215-1330**

No major change. No ^{131}I. Plume at 500' and one mile between 030 and 060 maximum value of 1.5 milliroentgens per hour. At three miles, plume between 030 and 060 maximum value of 1.5 milliroentgens per hour at 300' - top of plume at 2800' - bottom on ground. At ten miles maximum value of 0.2 milliroentgen per hour maximum at 1800'.

FLIGHT 3/31/79 **SHIPMAN** **TIME: 1520-1540**

At 500 feet and one mile, the plume was between 110 degrees and 140 degrees with a maximum value of 3 milliroentgens per hour.

At three miles, the top was at 1700 feet, the maximum at 500 feet of 1 milliroentgen per hour and the weather prevented finding the bottom.

The plume was shifting toward the south during the flight too rapidly to follow out a radial.

FLIGHT 3/31/79 **SHIPMAN** **TIME: 1843-1945**

Plume east between E and ESE with maximum value of 2 milliroentgens per hour. At three miles, the maximum value was 3 milliroentgens per hour occurring at 500 feet. The top of the plume was at 1000 feet.

The plume was followed out to a distance of eight miles which at the present wind speed of four knots represents the release history of the previous two hours.

The values decreased continuously to a value of 1 milliroentgen per hour at eight miles and 500 feet.

FLIGHT 3/31/79 **TIPTON** **TIME: 2100-2145**

Attempted to define the horizontal extent of the plume at various distances from the plant. All data were taken at an altitude of 500 feet. The results were as follows:

DISTANCE FROM PLANT	PLUME LOCATION	MAXIMUM LEVELS
1 mile	045° - 075°	0.8 milliroentgen per hour
3 miles	070° - 090°	1.0 milliroentgen per hour
10 miles	070° - 080°	0.15 milliroentgen per hour
15 miles	070° - 075°	0.15 milliroentgen per hour

The winds were slowly varying during the flight at speeds of three to five knots. The top of the plume was at 750 feet three miles from the plant and at 800 feet fifteen miles from the plant.

FLIGHT 4/1/79 **TIPTON** **TIME: 0030-0100**

At one mile out, the plume was detected between 085 degrees and 120 degrees with a maximum level of 1.0 milliroentgen per hour. Went out to three miles and had a hard time finding the plume at 500 feet. Top of cloud was at 600 feet. Maximum reading at 500 feet at three miles was 0.05 milliroentgen per hour. Wind was very light. Plume seemed to be hanging near the plant and quite near the ground. Due to heavy ground fog, could not fly below 500 feet.

FLIGHT 4/1/79 **MAGUIRE** **TIME: 0155-0245**

Launched early when we received word that holding tank was to be sampled at 0200. Sampling was delayed until 0300.

At one mile out plume was between 060 degrees and 110 degrees from plant. Maximum level was approximately 1 milliroentgen per hour. Heading out on 090 degrees radial from the plant levels were 1.5-2.0 milliroentgens per hour at two miles and dropped to 0.05-0.1 milliroentgen per hour at four miles east of plant. Width at four miles was approximately one-half mile. Top of plume was between 600 feet and 700 feet altitude.

FLIGHT 4/1/79 **MAGUIRE** **TIME: 0600-0700**

At one mile out and 500 feet altitude:

Maximum level: 2-3 milliroentgens per hour
Direction: 120 degrees at 0609 hours

At three miles out maximum levels were 0.4 to 0.6 milliroentgen per hour. Top of plume was approximately 800 feet altitude. Levels increased with decreasing altitude down to 300 feet. Edges were not well defined. Plume at three miles from plant was between 130 degrees and 170 degrees.

Winds changed from 220 degrees to 340 degrees during the flight which prevented "chasing" the plume.

FLIGHT 4/1/79 **SHIPMAN** **TIME: 0900-0940**

Plume was between 140 degrees and 165 degrees. At one mile and 500 feet, the maximum value was 3 milliroentgens per hour. At three miles the maximum value was 0.5 milliroentgen per hour. The top of the plume was at 1300 feet. The maximum occurred at 200 feet and the bottom was on the ground. Atten miles, the maximum value was 0.2 milliroentgen per hour.

The plume broadened substantially as the altitude increased.

FLIGHT 4/1/79 **SHIPMAN** **TIME: 1300-1346**

Wind 340 degrees at 8 knots. At one mile and 500 feet the plume was between 175 degrees and 192 degrees with a maximum value of 1 milliroentgen per hour.

At three miles the top of the plume was at 1800 feet, the maximum value of 0.5 milliroentgen per hour was at 500 feet and the bottom was at the ground.

FLIGHT 4/1/79 **BEERS** **TIME: 1408-1435**

Special mission in conjunction with gas transfer procedure. At one mile the plume was between 140 degrees and 180 degrees from the plant. Maximum readings were 3-4 milliroentgens per hour. Spectral measurements showed no change from previous (1300) flight. No additional measurements were made.

FLIGHT 4/1/79 **SHIPMAN** **TIME: 1515-1555**

At one mile and 500 feet, the plume was between 140 degrees and 170 degrees with a maximum value of 3 milliroentgens per hour. The highest reading was 13 milliroentgens per hour directly over the plant.

On leaving the plant the plume dropped and bounced at about three miles rising beyond that point.

After hitting the ground, the plume broke up into several fragments.

FLIGHT 4/1/79 **TIPTON/DAHLSTROM** **TIME: 1800-1900**

Flew a circle one mile out from plant at 500 feet altitude. The plume was between 220 degrees and 250 degrees with a maximum reading of 0.5 milliroentgen per hour. At three miles from the plant, at an altitude of 500 feet, the plume was between 240 degrees and 260 degrees with a maximum reading of 0.1 milliroentgen. Did an altitude spiral from 1000 feet to 500 feet at a distance of three miles from the plant. The top of the plume was at 600 feet. Poor visibility plus the closeness of the plume to the ground eliminated any chance of further defining the plume.

FLIGHT 4/1/79 **TIPTON** **TIME: 2110-2120**

Weather was extremely poor with rain and dense fog. Attempted to make a pass around the reactor at one mile. Had to come to within one-half to three-quarters mile of the plant to see it. Saw the plume between 270 degrees and 315 degrees. The maximum reading was only 0.1 milliroentgen per hour. The dense fog appeared to be pushing the plume right down on the ground. Impossible to get any additional information.

FLIGHT 4/2/79 **MAGUIRE** **TIME: 0300-0400**

Winds at start of flight were 140 degrees at 15 knots. They shifted during the flight to 120 degrees at 10 knots.

Maximum level was 1.5 milliroentgens per hour at one mile from the plant and 500 feet altitude. The plume was between 270 degrees and 315 degrees. At two miles from the plant and 500 feet altitude the maximum level was 0.5 milliroentgen per hour and the plume extended to 800 feet altitude. Width at two miles out was approximately one mile.

Bill Grant (NRC - Three Mile Island) informed us that a sample of the holding tank contents was taken between 0345 and 0400 hours. Between 0315 and 0400, the helicopter was in the vicinity of the plume at one mile from the plant and 500 feet altitude. The maximum level found was 1.5 milliroentgens per hour and no change was noticed during the flight.

FLIGHT 4/2/79 **MAGUIRE** **TIME: 0600-0615**

Bad weather and poor visibility limited flight time. Plume was northwest from plant. Maximum level was 1.0-1.5 milliroentgens per hour.

Winds 140 degrees at 15 knots.

FLIGHT 4/3/79 **BEERS** **TIME: 0905-1005**

Wind at start of flight was reported at 350 degrees at 13 knots. Maximum level measured was 1.7 milliroentgens per hour at approximately one-quarter mile from the plant. All reported readings are given at a nominal altitude of 500-700 feet AGL. At one mile the maximum reading was 0.8 milliroentgen per hour and the plume was 140-160 degrees from the plant. The plume appeared to meander and striate as distance from the plant increased. At 6.5 miles from the plant, readings above background were observed over an arc from 135 to 180 degrees. Peak readings at this distance were 0.3 milliroentgen per hour. Because of bad weather, measurements beyond this distance were not made.

At one-half mile from the plant the plume reached a maximum altitude of 1000' AGL; the plume was tracked to the ground.

Peak readings as a function of distance were as follows:

¼ mile	1.7 milliroentgens per hour
1 mile	0.8 milliroentgen per hour
3 miles	0.5 milliroentgen per hour
5 miles	0.4 milliroentgen per hour
6.5 miles	0.3 milliroentgen per hour

Spectral measurements showed no unnatural isotopes other than ^{133}Xe.

FLIGHT 4/3/79 **SHIPMAN** **TIME: 1200-1245**

0.3 milliroentgen accumulated dose. Wind 355 degrees at 10 knots. At one mile the plume was between 120 and 150 degrees. The maximum value of 2 milliroentgens per hour occurred at 500 feet. At three miles the top was at 1100 feet and the maximum at 200 feet with a value of 1.2 milliroentgens per hour. At 6.5 miles, the top was at 700 feet where the maximum also occurred. This maximum was 0.5 milliroentgen per hour. The plume showed a slight swing to the west between three and six miles. The plume seemed to be broken up into several fragments.

FLIGHT 4/3/79 **SHIPMAN** **TIME: 1500-1600**

0.1 milliroentgen per hour integrated dose. Wind was from 280 degrees at five knots. At one-half mile, the plume was between 100 and 120 degrees. At one-half mile, the top was at 1100 feet, the bottom at 300 feet with a maximum at 500 feet of 2 milliroentgens per hour. At three miles, the maximum was at 200 feet with a value of 0.5 milliroentgen per hour. At six miles the maximum was 0.5 milliroentgen per hour occurring at 150 feet.

FLIGHT 4/3/79 **DAHLSTROM** **TIME: 1815-1900**

A one mile radius circle was flown at an altitude of 500 feet and the plume was located between 160-180 degrees. The maximum exposure rate measured at 500' was 2 milliroentgens per hour. An altitude spiral was flown at one mile; the top of the plume was at 1250' and activity was still present at 150'. Apparently the plume extended to the ground. The levels in the plume varied from 1-2 milliroentgens per hour.

The maximum level measured at three miles in the same angular extent was 0.5 milliroentgen per hour.

A radial of 170 degrees was flown from three to six miles with the rate dropping to 0.1-0.2 milliroentgen per hour at six miles. An area of increased activity (1 milliroentgen per hour) was encountered at four miles, but was very small in extent. The plume appeared to be breaking up beyond six miles and was very difficult to track.

The winds were 360 degrees at 5 knots.

FLIGHT 4/3/79 **TIPTON/UH1N** **TIME: 2100-2145**

Defined the horizontal extent of the plume at distances of 1, 3, 6, and 10 miles from the plant at an altitude of 500 feet. The results were:

DISTANCE FROM PLANT	EXTENT OF PLUME	MAXIMUM LEVEL
1 mile	170° - 185°	0.5 milliroentgen per hour
3 miles	170° - 180°	0.5 milliroentgen per hour
6 miles	165° - 180°	0.5 milliroentgen per hour
10 miles	155° - 165°	0.5 milliroentgen per hour

Did an altitude spiral to determine the top of the plume at three miles from the plant. The top was at 600 feet.

FLIGHT 4/4/79 **DAHLSTROM** **TIME: 0000-0100**

Plume located between 220-255 degrees at one mile. Maximum rate was 1.1 milliroentgens per hour at 500'. Extent was 800-450 feet. At three miles a maximum rate of 0.5 milliroentgen per hour was measured between 215-230 degrees. At six miles a maximum rate of 0.3 milliroentgen was measured between 210-230 degrees. Another sector was flown over the river at one-half mile and a reading of 0.8 milliroentgen per hour was recorded between 210-185 degrees.

20 milliroentgens - pocket dosimeter.

FLIGHT 4/4/79 **MAGUIRE** **TIME: 0300-0330**

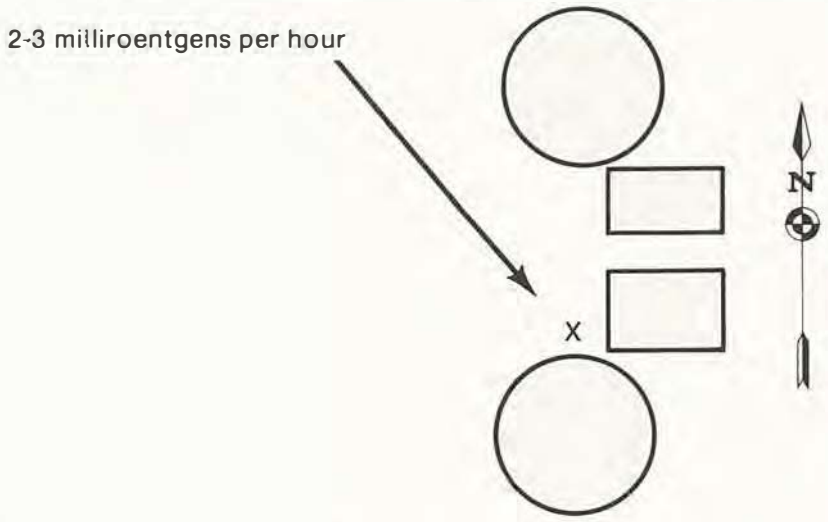
Winds reported to be 340 degrees at four knots. Highest level was 0.3 milliroentgen per hour at one mile from the plant and 500' altitude. Plume was between 200 and 220 degrees. Following a SE radial from the plant, the levels dropped to 0.1-0.2 milliroentgen per hour at three miles. Levels dropped below 0.05 milliroentgen per hour just past a ridge approximately three miles SE of plant. Edges were not well defined past the ridge.

Top of plume appeared to be between 600' and 700' at three miles.

FLIGHT 4/4/79 **MAGUIRE** **TIME: 0600-0640**

Winds reported to be calm. At one mile from plant maximum level was 1.0-1.2 milliroentgens per hour. The plume was SW of the plant at 500' altitude. Highest readings at three miles from the plant and 500' altitude were between 0.4 and 0.5 milliroentgen per hour. The plume was between 240 and 260 degrees out to ten miles where the maximum levels were approximately 0.2 milliroentgen per hour. Beyond ten miles the

plume edges were not well defined and the levels were less than 0.1 milliroentgen per hour. At three and ten miles from the plant the top of the plume was at approximately 850'. Flew a north-south line one-half mile from the plant. Peak reading of 2-3 milliroentgens per hour was obtained at the following location:



FLIGHT 4/4/79 **HARRIS** **TIME: 0900-0945**

Winds were 16 knots at 130 degrees. A circle of one-mile radius was flown at an altitude of 500'. The plume was positioned between 270 and 275 degrees with an exposure rate of 1.0 milliroentgen per hour. Several passes were made perpendicular to the plume at the three-mile point at altitudes of 200', 500', and 800'. This procedure was repeated at five miles out. In both instances the top of the plume was approximately 800'. The exposure levels were 0.5 milliroentgen per hour at the three-mile point and 0.1 milliroentgen per hour at the eight-mile point. The flight was flown with the H-500 REDAR II system with one crystal operating.

FLIGHT 4/4/79 **HARRIS** **TIME: 1030-1115**

Winds were 16 knots at 130 degrees. The 0900 flight was reflown because of inadequate system sensitivity. The procedure followed was identical to that of the 0900 flight. Four passes, perpendicular to the plume, were made at altitudes of 200', 500', and 800'. The top of the plume was approximately 1200' at the three-mile point and 800' at the ten-mile point. The position of the plume was 275 and 280 degrees. Because of the temporal proximity to the previous flight, no additional measurements were made.

FLIGHT 4/4/79 **SHIPMAN** **TIME: 1200-1230**

0.1 milliroentgen per hour accumulated dose. Wind 130 degrees at 10 knots. At one mile and 500' the maximum value was 0.7 milliroentgen per hour. The plume was between 270 and 280 degrees. The top was above 1400 feet and the peak value of 0.8 milliroentgen per hour occurred at the ground. At three miles, the maximum value occurred near the ground and was 0.4 milliroentgen per hour. The top of the plume was at 1400 feet.

FLIGHT 4/4/79 **EICHER** **TIME: 1522-1545**

The H-500C was flown to test the Microwave Ranging System. Gross count indicators were used instead of health instruments. A narrow plume was detected at 500' on the one-mile circle with an intensity of five times the background count at 270 degrees. Because of the visibility and ceiling the top was not located. At

two miles and 500' the plume was between 280 and 300 degrees with an average intensity of three times background. The lowest altitude flown at two miles was 100' and the plume was between 270 and 310 degrees at three times background with a peak of five times background on the 290 degree heading.

FLIGHT 4/5/79 **DAHLSTROM** **TIME: 0600-0645**

At 0600 winds were 250 degrees at 8 knots. At 0630 winds were 250 degrees at 4 knots. Plume edges were at 045 to 080 degrees on a radial out from site. Plume center was approximately 067 degrees on radial. Maximum reading at one mile was 0.3 milliroentgen per hour at 500'. Top of plume was at 1100' and the bottom was at 150' with readings varying between 0.2 milliroentgen per hour and 0.3 milliroentgen per hour. At six miles the readings between 045 and 080 degree radials from site were as follows:

ALTITUDE	MAXIMUM READING
500'	0.2 milliroentgen per hour
350'	0.4 milliroentgen per hour
300'	0.3 milliroentgen per hour
200'	0.3-0.4 milliroentgen per hour
Ground	0.1-0.2 milliroentgen per hour

At ten miles from the site, the plume became diffused and the maximum reading was 0.1 milliroentgen per hour.

FLIGHT 4/5/79 **HARRIS** **TIME: 0950-1040**

The plume was located between 125 and 130 degrees. The exposure rate at one mile was 0.3 milliroentgen per hour. Passes were flown at 200', 500', and 800' at three miles out. The exposure rates were 0.06, 0.05, and 0.06 milliroentgen per hour, respectively. At ten miles out the altitudes flown were 200', 500', and 800'. The exposure rates were 0.03, 0.05, and 0.04 milliroentgen per hour, respectively. The top of the plume was approximately 1100'. The winds were 320 degrees at 20 knots.

FLIGHT 4/5/79 **BEERS** **TIME: 1223-1327**

Winds were 15 knots at 330 degrees. Weather was clear. Flew one mile radius circle centered at TMI at an altitude of 500' AGL. Plume initially located between 110 and 120 degrees as measured from the plant. Maximum readings at one mile and 500' were 0.1 milliroentgen per hour. Center of plume was determined to be at approximately 300'. Plume was tracked for fifteen miles with the following results:

DISTANCE	EXPOSURE (AT 300' AGL)
1 mile	0.1 milliroentgen per hour
2 miles	0.1 milliroentgen per hour
5 miles	0.05 milliroentgen per hour
7 miles	0.05 milliroentgen per hour
10 miles	0.03 milliroentgen per hour
11 miles	0.025 milliroentgen per hour
15 miles	0.03 milliroentgen per hour

At five miles the height of the plume was determined to be 3300' AGL with the bottom at 150'. Plume was very narrow (less than 5 degrees). An altitude spiral was flown at approximately 1.5 miles from the plant. Exposure was very constant at 0.1 milliroentgen per hour from ground level to over 1500'. No man-made isotopes other than ^{133}Xe were identified.

FLIGHT 4/5/79 **BEERS** **TIME: 1515-1615**

Winds were 25 knots at 320 degrees; the weather was clear. Flew one mile radius circle at an altitude of 500' AGL. Plume located between 120 and 135 degrees as measured from the plant. Maximum readings observed at one mile and 500' were less than 0.1 milliroentgen per hour. Plume was tracked to a distance of eight miles. At a distance of 1.5 miles the plume reached an altitude of 1600' and was tracked to the ground.

FLIGHT 4/5/79 **BEERS** **TIME: 1649-1831**

A special mission launched in conjunction with transfer procedure. Winds were 14 knots at 340 degrees. Racetrack pattern was flown in close proximity to the plant on the downwind side. Maximum readings were less than 0.2 milliroentgen per hour. The plume was tracked to a distance of ten miles where its peak altitude was 2000'. The center of the plume was at 112 degrees from the plant.

FLIGHT 4/5/79 **TIPTON** **TIME: 2120-2150**

At one mile from the plant, at an altitude of 500 feet, the plume was between 015 and 060 degrees with a maximum reading of 0.05 milliroentgen per hour. At three miles from the plant, at an altitude of 500 feet, the plume was between 020 and 060 degrees. The levels going through the plume varied from 0.01 to 0.03 milliroentgen. (Note: At the three mile distance the levels were too low for the Geiger counter. The readings were made with the Baird-Atomic scintillation counter.) At three miles from the plant the top of the plume was around 600 feet. The helicopter went down to 300 feet without seeing any significant changes in the radiation readings.

FLIGHT 4/5/79 **TIPTON** **TIME: 2325-2345**

A special mission was launched at the request of NRC (at 2315) to monitor a transfer process scheduled for 2330. The flight was cancelled at 2340 when the transfer was delayed.

FLIGHT 4/6/79 **BURSON** **TIME: 0600-0710**

Water transfer inside the plant began about 0555 and expected to take about five hours. Winds were at 310 degrees at 20 knots. We found the plume at 95 degrees, very difficult to find because of strong winds. Highest reading was about 0.15 milliroentgen per hour at about 500 feet and about one mile. Flight was very rough. We landed at about two miles and 100 degrees and noted that the plume was near ground. We flew between one and three miles and noted readings as high as 0.3 milliroentgen per hour, generally from the surface up to 900 feet MSL, at 90-95 degrees. On the way back, winds picked up, gusts up to 43 knots.

FLIGHT 4/6/79 **TIPTON/FRANKHAUSER** **TIME: 1810-1845**

At an altitude of 500 feet and one mile from the plant, the plume was between 120-140 degrees with maximum reading of 0.05 milliroentgen per hour. At three miles from the plant at an altitude of 500' the plume was located between 120-140 degrees with a maximum reading of 0.02 milliroentgen per hour. The top of the plume was at 1300'. NOTE: All readings were taken with the Baird-Atomic scintillation counter because of the very low levels measured.

FLIGHT 4/6/79 **TIPTON** **TIME: 2055-2125**

At one mile from the plant and 500' altitude, the plume was between 100-140 degrees with a maximum reading of 0.05 milliroentgen per hour. Three miles from the plant, at an altitude of 500', the plume was between 110-130 degrees with a maximum reading of 0.05 milliroentgen per hour. The top of the plume was at 1300' three miles from the plant. All readings were taken with the Baird-Atomic scintillation counter due to the low levels.

FLIGHT 4/7/79 **MAGUIRE** **TIME: 0600-0645**

Winds were reported as 330 degrees at 15 knots. The highest level at one mile from the plant and 500' altitude was 0.04 milliroentgen per hour. The plume was located to the southeast of the plant at a heading of approximately 130 degrees. At three miles southeast of the plant, the highest exposure levels were between 0.03 and 0.04 milliroentgen per hour and extended from the ground to 1700' altitude. Plume width at three miles and 500' altitude was less than one mile. At ten miles the highest exposure levels were less than 0.015 milliroentgen per hour. The top of the plume was at approximately 1500'.

FLIGHT 4/7/79 **MAGUIRE** **TIME: 1030-1100**

At one mile from the plant on a heading of 130-140 degrees, the maximum level was 0.05 milliroentgen per hour at 500' altitude. A peak level of 0.015 milliroentgen per hour was found at three miles from the plant and 800' altitude at a heading of 125 degrees. At ten miles, heading 125 degrees, exposure rates were below 0.01 milliroentgen per hour. The top of the plume was at approximately 1000' altitude.

FLIGHT 4/7/79 **TIPTON** **TIME: 1805-1845**

At one mile from the plant the plume was between 140 and 150 degrees. The maximum reading at an altitude of 500 feet was 0.05 milliroentgen per hour. At three miles from the plant the plume was between 130 and 140 degrees with a maximum reading of 0.015 milliroentgen per hour at 500 feet altitude. The top of the plume was about 1500 feet. At six miles from the plant the plume was still at 135 degrees from the plant with a maximum reading of 0.01 milliroentgen per hour. All readings were made with Baird-Atomic scintillation counter.

FLIGHT 4/7/79 **BURSON** **TIME: 2255-2335**

Called out because NRC called; a vent reading had increased by a factor of ten. Winds calm. Plume from 140 to 160 degrees; maximum 0.1 milliroentgen per hour at one-half to one mile, 380' altitude; another reading was 0.2 milliroentgen per hour zigzagged out to four miles; found maximum at 0.4 milliroentgen per hour, generally read from 0.05 to 0.2 between 160 to 190 degrees; made a cut three miles, heading 160 degrees.

ALTITUDE	MILLIROENTGEN PER HOUR
200ft	0.040
300ft	0.045
400ft	0.050
500ft	0.030
600 ft	0.025
700ft	0.020
800ft	0.050
900ft	0.030
1000 ft	0.015
1100 ft	0.012
1200 ft	0.010

Went to one mile - peaked at 0.2 milliroentgen per hour at 145 degrees. Landed at 2335 and called NRC to give results. NOTE: Scintillator read about a factor of two higher than the Geiger counter.

FLIGHT 4/7/79 - 4/8/79 **BURSON** **TIME: 2350-0050**

NRC called - they began relieving pressure at the reactor and requested helicopter to be in air immediately. We circled the plant at one-half mile several times, then zigzagged downwind from one-quarter mile to one-half mile, generally at 500 feet. Initially the wind was blowing due south - wide plume plus or minus 20 degrees. Initially, maximum readings were 0.2 to 0.5 milliroentgen per hour increasing to 1.0 milliroentgen per hour, later decreasing to 0.2 to 0.5 milliroentgen per hour. Flight lasted approximately forty-five minutes. At end of flight, winds shifted to 190 degrees. Landed at 0050 and called NRC to inform them of results - obvious increase in levels - up to 1.0 milliroentgen per hour. They requested us to stand by.

FLIGHT 4/8/79 **MAGUIRE** **TIME: 0620-0700**

The maximum level in the plume was 0.3 milliroentgen per hour at an altitude of 650-700 feet heading 200 degrees one mile from the plant. Top of the plume at one mile was between 900' and 1000' altitude. At 2.5 miles from the plant heading 190 degrees a peak of 0.03 milliroentgen per hour was noted at 850' altitude. The top of the plume occurred at 1000' altitude.

FLIGHT 4/8/79 **MAGUIRE/JOBST** **TIME: 0900-0945**

At one mile from the plant and 500' altitude the maximum level was 0.03-0.04 milliroentgen per hour heading 170 degrees. Top of plume was at approximately 1100' altitude. Three miles from the plant the maximum level was 0.013 milliroentgen per hour on a heading of 165 degrees. The plume was not well defined out further than one mile from the plant. The exposure rate peaked at two different headings (165 and 190 degrees) three miles from the plant.

FLIGHT 4/8/79 **STUART/TIPTON** **TIME: 1805-1830**

At one mile from the plant the plume was between 270 and 280 degrees. The maximum reading at 500 feet altitude was 0.05 milliroentgen per hour. Three miles from the plant the plume was between 270 and 285 degrees with a maximum reading at 500 feet altitude of 0.03 milliroentgen per hour. The top of the plume was at 1100 feet three miles from the plant and extended to the ground. At six miles from the plant the plume was between 270 and 280 degrees with a maximum reading of 0.015 milliroentgen per hour.

FLIGHT 4/9/79 **JOBST/FRANKHAUSER** **TIME: 1238-1308**

Wind 90 degrees at 8 knots; several passes were made at altitudes between 400 and 500 feet. The release appeared to be wandering around. Peaks were found at three different angles with respect to TMI: 235 degrees (1.5 milliroentgens per hour), 250 degrees (2.0 milliroentgens per hour), and 270 degrees (1.5 milliroentgens per hour). Predominant direction: 250 degrees. All these were measured along an arc one mile from the plant. Because of very heavy clouds, right down to the ground, it was impossible to fly along the plume to determine its extent and intensity downwind. Only 81 keV ^{133}Xe was seen.

Above reported measurements were made with Baird-Atomic Scintillation ratemeter S/N 384. Measurements also were made with the Ludlum Model 3 GM Counter #2 - Peak readings agreed with the scintillation counter. Measurements were made with the beta window open. With the probe inside and outside the helicopter, readings were identical.

FLIGHT 4/9/79 **JOBST** **TIME: 1805-1848**

Conditions: rain, wind at 280 degrees at 20 mph. A maximum reading of 1 milliroentgen per hour was observed at 120 degrees from TMI at a distance of one mile, altitude of 500 feet. At three miles, a maximum of 0.07 milliroentgen per hour was observed at 95 degrees, 500 feet altitude. A later pass at 1000 feet yielded a maximum of 0.03 milliroentgen per hour at 90 degrees. At four miles, a maximum of 0.07 milliroentgen was measured at 105 degrees, 500 feet altitude. At six miles a maximum of 0.12 milliroentgen per hour was measured at 100 degrees, 500 feet altitude. These data were measured with the Baird Atomic scintillator. Analyzer spectrum indicated that only ^{133}Xe was observed.

FLIGHT 4/10/79 **JOBST** **TIME: 0627-0800**

Conditions: clear, 15 mph wind from 310 degrees. Because of strong consistent winds, the effluent from Three Mile Island was readily observable at 140 plus or minus 5 degrees from the plant. The intensity had dropped to 0.007 milliroentgen per hour at a distance of 6.5 miles. At 0730 hours, the time of an announced release, the exposure rate at 1.5 miles was 0.06 milliroentgen per hour. The release could be measured to 0.007 milliroentgen per hour at a maximum altitude of 1600 feet above ground. Practically speaking, the top of the plume was at 1000 feet. Exposure rate increased from 0.025 milliroentgen at 1000 feet to 0.1 milliroentgen per hour at 200 feet above ground. This vertical profile was made at a distance of 1.0 mile from the reactor, at an angle of 140 degrees.

FLIGHT 4/10/79 **FRANKHAUSER** **TIME: 1833-1913**

Conditions: clear, estimated winds at 340 degrees at 10 knots. Plume location was consistent with the prevailing winds. We flew a circle at one mile distance, 500 feet altitude. Reading was 0.015 milliroentgen per hour at bearing 120 degrees relative to the plant. An altitude spiral was performed at one mile range. Extent of the plume was essentially 600-800 feet altitude maximum (0.003-0.004 milliroentgen per hour) on down to 100 feet altitude (0.025-0.030 milliroentgen per hour), bearing 120 degrees from the plant. We flew out at 200 feet altitude from the plant along bearing 120 degrees and as distance increased, the plume began to curve toward the south. Readings vs range from the plant (maximum values obtained from a cut through the plume) were as follows:

RANGE (MILES)	READING (MILLIROENTGEN PER HOUR)	HEADING
1.5	0.013	120 degrees
2.0	0.010	120 degrees
2.5	0.0085	135 degrees
5.0	0.008-0.010	130-140 degrees*

* At this distance the plume was quite diffuse.

FLIGHT 4/11/79 **JOBST** **TIME: 0917-0952**

Conditions: Clear, high, thin clouds. Olmstead AFB wind 240 degrees at six MPH. Plant conditions: Very light, variable winds, 90 degrees. A perimeter flight two miles from the reactor at 500 feet altitude showed extremely low activity on the Baird-Atomic scintillator: 0.003 milliroentgen per hour. A one-mile circuit of the reactor showed similarly low levels. A pass 1000 feet from the reactor showed levels increasing from 0.002 milliroentgen per hour at 330 degrees to 0.025 at 270 degrees, and decreasing to 0.002 milliroentgen per hour at 220 degrees. This pass was made at 150 feet above the river. A second pass, again at 1000 feet from the reactor, showed a maximum level of 0.012 milliroentgen per hour at 290 degrees and 100 feet

above the river. These measurements may represent gamma shine from the containment vessel and auxiliary buildings. The spectrum analyzer did not show the ^{133}Xe peak normally associated with the reactor plume; the analyzer showed only the Compton shape of normal background radiation.

FLIGHT 4/11/79 **STUART** **TIME: 1700-1743**

Conditions: High clouds; winds five mph, 070 degrees. Found no indication of plume over 360 degree circle on approximately one mile radius at 500 feet above ground level. Visually attempted to guess plume path. Flew this course from about four miles out with no increase in radiation levels. Radiation level at 400 feet above ground level and 500 yards from buildings at 310 degrees was 0.01 milliroentgen per hour. However, similar readings were observed at same distance at approximately 90 degrees to this angle, indicating we were detecting shine. Hovered in what was believed to be plume at 800 feet above ground level, 100 yards from reactor, and observed 0.015 milliroentgen per hour. Readings quoted thus far were measured on Baird Atomic instrument. Spectral data on LLL analyzer gave no indication of airborne fission products.

FLIGHT 4/12/79 **JOBST** **TIME: 0938-1016**

Conditions: Intermittent rain, light and variable winds. At 0943 hours, a circuit of Three Mile Island was begun at three miles from the facility, 700 feet altitude above ground. A maximum reading of 0.008 milliroentgen per hour was observed at 270 degrees with respect to Three Mile Island. A one-mile circuit showed a maximum reading of 0.030 milliroentgen per hour at 315 degrees, 500 feet altitude. Another one-mile circuit showed a maximum of 0.008 milliroentgen per hour at 300 degrees, 300 feet altitude. The plume was missing at 100 and 200 feet. A vertical plume penetration at one mile from Three Mile Island along a 300 degree bearing gave the following results:

EXPOSURE RATE (MILLIROENTGEN PER HOUR)	ALTITUDE (FT)
0.002	1000
0.002	900
0.010	800
0.018	700
0.015	600
0.010	500
0.006	450
0.006	400
0.003	350
0.003	250
0.002	200
0.002	150
0.002	100

At approximately 700 feet above ground, the plume could be tracked along the 300 degree radial to a distance of 4.5 miles from the plant. No evidence of plume could be found at five or six miles. The spectrum analyzer showed only ^{133}Xe in the plume.

FLIGHT 4/12/79 **JOBST** **TIME: 1510-1603**

Conditions: Intermittent rain, considerable fog, light and variable winds. Many passes completely around the reactor were made at various altitudes (300-600 feet above ground level). No readings above background level (0.003 milliroentgen per hour) were observed for distances as close as one-eighth mile. A maximum reading of 0.010 milliroentgen per hour was measured at 270 degrees with respect to the reactor, but only at a distance of less than 1000 feet, where direct shine from the reactor was possible. No evidence of plume was obtained during this flight. No ^{133}Xe was observed on the spectrum analyzer.

FLIGHT 4/13/79 **JOBST** **TIME: 0908-0940**

Conditions: clear; high, thin clouds; winds 110-140 degrees at 14-16 mph. Two trips around the reactor were made at distances of three miles and one mile, both at about 500 feet above ground level. Only background exposure rates of 0.002 ± 0.001 milliroentgen per hour were measured. A pass from north to south, parallel to the river, at about 1000 feet from the reactor (altitude 250 feet AGL) showed a maximum of 0.010-0.011 milliroentgen per hour at 260-270 degrees with respect to the reactor. In a hover at 300 feet AGL, about 1000 feet or less from the reactor, rates from 0.010 to 0.030 milliroentgen per hour were observed on the west side of the reactor (250 to 290 degrees). These measurements appear to be caused by gamma penetration of the containment vessel. A short spectrum showed only the Compton continuum, with no trace of ^{133}Xe.

FLIGHT 4/13/79 **BEERS** **TIME 1454-1533**

A special flight was flown at the request of the NRC in conjunction with the opening of shielded doors in the auxiliary building. Helicopter was on station prior to the reported time of opening at 1502.

Winds were 14 knots from 130 degrees. Helicopter hovered at approximately 300 meters downwind from the auxiliary building at altitudes varying from 300 feet to 600 feet. Peak readings were approximately 0.03 milliroentgen per hour.

A thirty minute gamma ray spectrum using the portable spectrum analyzer was taken. The spectrum showed no identifiable radioisotopes and was indicative of a scattered fission source.

At the conclusion of the flight, it was noted by the NRC that only one set of double doors had been opened.

FLIGHT 4/13/79 **STUART** **TIME: 2145-2230**
2252-2335

Purpose: Monitor drawing of primary reactor coolant sample. Weather: Raining on take-off; wind 130°/14. Flight pattern: Race track course on downwind side reactor at 500 feet to 800 feet AGL at one-half mile to three-quarters mile distance. Oval bounded by 240 and 300 degrees. Results: Flight #1—2145-2230—Essentially background ~0.003 milliroentgen per hour to 0.005 milliroentgen per hour. Flight #2—2252-2335—Possibility of plume contact at ~one-half mile distance between 250 and 290 degrees, 500 feet AGL, maximum reading 0.007 milliroentgen per hour - time: 2323.

FLIGHT 4/14/79 **JOBST** **TIME: 1138-1221**

Conditions: Clear; light, variable winds. At a distance of one mile from the reactor, 250 feet altitude, a slightly elevated exposure rate of 0.004-0.005 milliroentgen per hour could be measured at an angle of 150 degrees with respect to Three Mile Island. At the same altitude a maximum level of 0.012 milliroentgen per hour could be measured at one-quarter mile, bearing 190 degrees. By dropping through the plume from approximately 1000 feet above ground, 170 degree bearing, it was observed that the plume could be

measured from 450 to 250 feet. The plume maximized at, perhaps, 270 feet altitude, bearing 170 degrees, about one-quarter mile from the reactor. A hovering pattern was maintained in this position for sixteen minutes while an air sample was obtained. Exposure rates during hover varied from 0.010-0.040 milliroentgen per hour. Only ^{133}Xe was observed on the spectrum analyzer.

FLIGHT 4/14/79 **STUART** **TIME: 2152-2350**

Purpose: supposedly an Iodine flight. Good news: none. Bad news: analyzer cable bad- no spectral data.

Initially attempted to hover in direction of plume; observed 0.03 milliroentgen per hour at 2230 at 330 degrees and one-quarter mile radius. Hover was for purpose of gathering spectral data - noted analyzer failure. Corrected purpose of flight to plume definition.

Made two passes at approximately one-half mile radius at 500 feet and 750 feet between 2235 and 2244 and noted essentially background levels. Pass at 300 feet and one-half mile gave greater than 0.030 milliroentgen per hour at 330 degrees. Tracked plume to two and one-half miles at ~345 degrees to min. of 0.015 milliroentgen per hour and 300 feet altitude (time: 2247). Return gave ~0.03 milliroentgen per hour at 350 degrees and one mile at 2110 (300 feet altitude).

Attempted plume track at 500 feet altitude and detected maximum 0.025 milliroentgen per hour three and one-half miles out at 350 degrees to 360 degrees. Noted wind change (we thought). However, east and west passes gave maximum at 360 degrees of 0.030 milliroentgen per hour at 300 feet altitude and one-fourth mile out. Same altitude one mile out gave 0.025 milliroentgen per hour. Same altitude one and a half miles out gave 0.015 milliroentgen per hour at 20 degrees. Indicating change of wind direction—time ~2332.

Made passes at 300 feet and got ~0.03 milliroentgen per hour between 50 degrees and 70 degrees at one-half mile.

Passes at one mile distance and between 300 feet and 500 feet gave greater than 0.025 milliroentgen per hour at 60 and 70 degrees—time ~2340.

Pass at 750 feet at one mile gave 0.08 milliroentgen per hour at 80 degrees at time 2342.

FLIGHT 4/15/79 **FREED** **TIME: 1720-1815**

Maximum plume reading at one-half mile, 300 feet altitude, 120 degrees radial, 0.013 milliroentgen per hour.

1 mile	500 feet	0.006 milliroentgen per hour
1 mile	250 feet	0.009 milliroentgen per hour
1 mile	1000 feet	Negative
1 mile	1500 feet	Negative
3 miles	1500 feet	Negative
3 miles	1000 feet	0.002 milliroentgen per hour
3 miles	500 feet	0.005 milliroentgen per hour
3 miles	250 feet	0.008 milliroentgen per hour

FLIGHT 4/16/79 **BEERS** **TIME: 0908-0951**

Weather overcast; winds at 12 knots from 310 degrees. Flew one mile circle at 500' AGL. No reading above background observed. Flew one-quarter mile circle at 500 feet; saw no evidence of plume; however, noted two areas: one due west and one due south of number two, yielding readings as high as 0.030 milliroentgen

per hour. Spectral measurements implied scattered fission source, no indication of ^{133}Xe. These areas of elevated readings have been noted on other flights. Appears to be either shine from reactor buildings or other materials on the ground. Because no Xenon or other gaseous effluents were noted, no air sample was taken.

FLIGHT 4/16/79 **BEERS** **TIME: 1039-1106**

We were specifically requested by the NRC to collect air sample downwind from number two. Helicopter hovered approximately 100 meters from number two at an altitude of 250 feet for 15 minutes. Air sample taken and turned over to BNL personnel. Results not available at this time.

FLIGHT 4/16/79 **BEERS** **TIME: 1549-1640**

Special flight at the request of NRC to monitor potential airborne releases during some procedure. Weather clear with winds from 310 degrees (at Olmstead AFB) at 18 knots. Flew one-quarter mile circle around plant; no obvious presence of plume. Determined wind direction in immediate vicinity of plant, hovered approximately 100 meters from Reactor #2 at an altitude of 250 feet. Highest readings were approximately 0.01 milliroentgen per hour. Spectral data indicated no airborne radioisotopes. Fifteen minute air sample taken and turned over to BNL. Results not available at this time. Located storage containers approximately one-half mile south of #2 that show some radioactivity. A potential source of confusion when working in this area. Spectrum taken indicates a scattered fission source.

FLIGHT 4/17/79 **FREED** **TIME: 0900-1000**

H-500 flight to test MRS coverage. Incidental measurements with hand-held survey meters yielded no significant readings.

FLIGHT 4/17/79

Since there was no callout and an earlier H-500 yielded negative results, the normal BO-105 flight for the day was scrubbed.

FLIGHT 4/18/79 **BEERS** **TIME: 0638-0741**

Special flight flown at the request of the NRC. Weather clear, winds from 310° and 9 knots. Plume detected out to approximately one and one-half miles at 110° from the plant (#2 Reactor). Peak readings at 200 meters from #2 were 0.020 milliroentgen per hour at an altitude of 300' AGL. A fifteen minute air sample was taken at this location. The sample is being analyzed by the EPA. Spectral measurements yielded positive ^{133}Xe results.

FLIGHT 4/19/79 **BEERS** **TIME: 1805-1855**

Weather clear; winds from 350° at 5 knots, as reported from Olmstead tower. Flew close in perimeter flight around island at altitude of 500 feet above ground level and nominal distance from #2 of one-quarter mile. A trace of a plume was detected south of #2 between 150° and 170°. Peak readings were 0.005 milliroentgen per hour, approximately twice background for the area. A 30 minute spectrum was recorded which suggested traces of ^{133}Xe. A 30 minute air sample was taken with the filter turned over to EPA and thereafter to the NRC. Results are not available at this time.

FLIGHT 4/20/79 **BEERS** **TIME: 0821-0912**

Weather clear; winds from 290° at 8 knots, as reported from Olmstead tower. Flew close in perimeter flight around the island at altitude of 500 feet above ground level and nominal distance from #2 of one-quarter mile. A trace of a plume was detected east of #2 at 080°. Maximum detectable readings were 0.008 milliroentgen per hour at an altitude of 350 feet above ground level and a distance of approximately 250 meters from #2. Both a 30 minute spectrum and a 30 minute air sample were taken from 0839-0909. Spectral measurements were inconclusive, but no ^{133}Xe was evident. The filter is being read successively by both EPA and the NRC. The results are not ready at this time.

FLIGHT 4/20/79 **SHIPMAN** **TIME: 1740-1800**

Flight to monitor filter changeover. All background.

FLIGHT 4/20/79 **SHIPMAN** **TIME: 2225-2300**

All background.

FLIGHT 4/20/79 - 4/21/79 **SHIPMAN** **TIME: 2330-0020**

All background.

FLIGHT 4/21/79 **SHIPMAN** **TIME: 1513-1534**

Flight to monitor purge of gas holding tank. All background.

FLIGHT 4/21/79 **SHIPMAN** **TIME: 2120-2200**

All background.

FLIGHT 4/22/79

No flights

FLIGHT 4/23/79 **SHIPMAN** **TIME: 2033-2100**

Reported spill in plant. Nothing above background.

FLIGHT 4/24/79 **SHIPMAN** **TIME: 1300-1350**

All background.

FLIGHT 4/24/79 **SHIPMAN** **TIME: 1700-1745**

All background.

FLIGHT 4/24/79 **SHIPMAN** **TIME: 1840-1920**

All background.

FLIGHT 4/25/79 **SHIPMAN** **TIME: 0900-1000**

All background.

FLIGHT 4/26/79

No flights

FLIGHT 4/27/79 **SHIPMAN** **TIME: 1345-1540**

Utility was "steaming" steam generator. Flew with A-100 pod system. Plume was 323°. At one-half mile the exposure rates were 0.05-0.1 milliroentgen per hour. At 10 miles the count rates were three times background. An air sample was taken.

FLIGHT 4/27/79 **SHIPMAN** **TIME: 1545-1630**

Levels were same, location same. Saw no I-131.

FLIGHT 4/27/79 **SHIPMAN** **TIME: 1720-1750**

Location same. Measured 0.03 milliroentgen per hour at 1 mile.

FLIGHT 4/28/79 **SHIPMAN** **TIME: 0130-0220**

Called out because of "I-131 spike" which turned out to be an error. Plume was south of TMI and read six times background at one-half mile.

FLIGHT 4/28/79 **SHIPMAN** **TIME: 1110-1231**

All background.

FLIGHT 4/29/79 **SHIPMAN** **TIME: 1705-1807**

Routine flight. All background.

FLIGHT 4/30/79 **SHIPMAN** **TIME: 1355-1430**

Routine flight. All background.

FLIGHT 5/1/79 **SHIPMAN** **TIME: 1810-1842**

Routine flight. All background.

FLIGHT 5/1/79 **SHIPMAN** **TIME: 2057-2000**

Reported "I-131 pubb", plume between 130° and 190°. Exposure values were (in milliroentgen per hour): three miles = 0.010; one-half mile = 0.018; one-quarter mile = 0.022. Iodine 131 was detected.

FLIGHT 5/1/79 **SHIPMAN** **TIME: 2300-2345**

All background.

FLIGHT 5/2/79 **SHIPMAN** **TIME: 1425-1512**

Routine flight. All background.

FLIGHT 5/3/79 **SHIPMAN** **TIME: 1753-1841**

Plume was at 330°. Maximum level at 1.5 miles out and 300 feet altitude was 0.015 milliroentgen per hour. I-131 was detected. At end of flight levels were down to background in the same location.

FLIGHT 5/4/79 **SHIPMAN** **TIME: 0755-0830**

Report of a leak. At one-half mile and 300 feet altitude - 8 microroentgens per hour. At three miles and 300 feet altitude - background. At 0830 at one-half mile and 300 feet - background.

FLIGHT 5/4/79 **SHIPMAN** **TIME: 1315-1341**

Filling a make-up tank. At one-half mile and 300 feet altitude - background. At site boundary - 1.5 times background.

FLIGHT 5/4/79 **SHIPMAN** **TIME: 2139-2157**

Plume at 150°. At one-half mile and 500 feet altitude - 25 microroentgens per hour. At one mile and 500 feet altitude - 15 microroentgens. At boundary and 300 feet altitude - 30 microroentgens per hour. Saw I-131.

FLIGHT 5/5/79 **SHIPMAN** **TIME: 0830-0848**

Called out for filling make-up tank. All background.

FLIGHT 5/5/79 **SHIPMAN** **TIME: 1020-1035**

All background.

FLIGHT 5/5/79 **SHIPMAN** **TIME: 1348-1515**

Monitoring primary coolant sampling. All background.

FLIGHT 5/6/79 **SHIPMAN** **TIME: 1215-1229**

Monitor pressurization of feed tank. All background.

FLIGHT 5/6/79 **SHIPMAN** **TIME: 1542-1605**

Suspected release. All background.

FLIGHT 5/6/79 **SHIPMAN** **TIME: 1639-1650**

Filling feed tank. All background. Filling procedure went from 1630-1900.

FLIGHT 5/6/79 **SHIPMAN** **TIME: 1735-1739**

All background.

FLIGHT 5/6/79 **SHIPMAN** **TIME: 1745-1800**

All background.

FLIGHT 5/6/79 **SHIPMAN** **TIME: 1830-1838**

All background.

FLIGHT 5/6/79 **SHIPMAN** **TIME: 1905-1913**

All background.

FLIGHT 5/7/79 **SHIPMAN** **TIME: 1135-1153**

All background.

FLIGHT 5/8/79 **SHIPMAN** **TIME: 1710-1736**

All background.

FLIGHT 5/9/79 **SHIPMAN** **TIME: 2017-2032**

Routine flight. All background.

FLIGHT 5/10/79 **SHIPMAN** **TIME: 1720-1733**

Monitoring primary coolant sample. All background.

FLIGHT 5/10/79 **SHIPMAN** **TIME: 1920-1950**

All background.

FLIGHT 5/11/79 **SHIPMAN** **TIME: 1642-1700**

Routine flight. All background.

FLIGHT 5/12/79 **SHIPMAN** **TIME: 1410-1425**

Routine flight. All background.

FLIGHT 5/13/79 **SHIPMAN** **TIME: 1849-1906**

Routine flight. All background.

FLIGHT 5/14/79 **SHIPMAN** **TIME: 1855-1930**

Routine flight. All background.

FLIGHT 5/15/79 **SHIPMAN** **TIME: 1940-2012**

Routine flight. All background.

FLIGHT 5/16/79 **SHIPMAN** **TIME: 1328-1425**

Callout due to 100-fold increase in I-131 stack monitor indication. Not seen by ground sampling. Wind from 330° at 12 mph. All background out to 10 miles.

FLIGHT 5/16/79 **SHIPMAN** **TIME: 1830-1845**

All background.

FLIGHT 5/17/79 **SHIPMAN** **TIME: 1840-1855**

Routine flight. All background.

FLIGHT 5/18/79 **SHIPMAN** **TIME: 1940-2000**

Routine flight. All background.

FLIGHT 5/19/79 **SHIPMAN** **TIME: 2100-2120**

Routine flight. All background.

FLIGHT 5/20/79 **SHIPMAN** **TIME: 1035-1100**

Called out to check on continuing stack releases. All background.

FLIGHT 5/20/79 **SHIPMAN** **TIME: 2320-2340**

All background.

FLIGHT 5/21/79 **SHIPMAN** **TIME: 1937-2000**

Routine flight. All background.

FLIGHT 5/21/79 **SHIPMAN** **TIME: 2106-2135**

Called out for ground level release. All background.

FLIGHT 5/22/79 **SHIPMAN** **TIME: 1030-1104**

Routine flight. All background.

FLIGHT 5/22/79 **SHIPMAN** **TIME: 1925-2010**

Monitoring filling of make-up tank. All background.

FLIGHT 5/23/79

No flights

FLIGHT 5/24/79 **SHIPMAN** **TIME: 1945-2003**

Venting of tank. All background.

FLIGHT 5/25/79 **SHIPMAN** **TIME: 1130-1225**

Release in progress. Elevated levels. Approximately twice background was noted below 100 feet. Radon and daughter products were identified as the isotopes present.

FLIGHT 5/26/79 **SHIPMAN** **TIME: 1820-1845**

Routine flight. All background.

FLIGHT 5/27/79

No flights due to bad weather.

FLIGHT 5/28/79 **SHIPMAN** **TIME: 1932-2005**

Routine flight. All background.

FLIGHT 5/29/79 **SHIPMAN** **TIME: 1916-2000**

Routine flight. All background.

FLIGHT 5/30/79 **SHIPMAN** **TIME: 1900-1940**

Routine flight. All background.

FLIGHT 5/31/79 **SHIPMAN** **TIME: 1727-1740**

Routine flight. All background.

FLIGHT 6/1/79 **SHIPMAN** **TIME: 1802-1846**

Routine flight. All background.

FLIGHT 6/2/79 **SHIPMAN** **TIME: 1530-1603**

Dumping waste gas holding tank. Continuous releases of 9 cfm all day. All background.

FLIGHT 6/3/79

Still releasing gas. No flights due to weather.

FLIGHT 6/4/79 **SHIPMAN** **TIME: 1425-1558**

Called out for positive pressure in reactor building. All background.

FLIGHT 6/5/79 **SHIPMAN** **TIME: 1212-1257**

Called out because of release. All background.

FLIGHT 6/5/79 **SHIPMAN** **TIME: 1802-1840**

Routine flight. All background.

FLIGHT 6/6/79 **SHIPMAN** **TIME: 0950-1015**

Called outto monitor purge of Unit #1 containment. All background.

FLIGHT 6/7/79 **SHIPMAN** **TIME: 1724-1740**

Routine flight. All background.

FLIGHT 6/8/79 **SHIPMAN** **TIME: 1705-1730**

Routine flight. All background.

FLIGHT 6/9/79 **SHIPMAN** **TIME: 1511-1528**

Called out to monitor filling of make-up tank. All background.

FLIGHT 6/10/79 **SHIPMAN** **TIME: 1916-1933**

All background.

FLIGHT 6/11/79 **SHIPMAN** **TIME: 1902-1920**

Routine flight. All background.

FLIGHT 6/12/79 **SHIPMAN** **TIME: 1330-1405**

Routine flight. All background.

FLIGHT 6/13/79 **SHIPMAN** **TIME: 1700-1734**

Routine flight. All background.

FLIGHT 6/14/79

On standby for water transfer. No flights.

FLIGHT 6/15/79 **SHIPMAN** **TIME: 2140-2215**

Routine flight. All background.

FLIGHT 6/16/79 **SHIPMAN** **TIME: 1700-1735**

Routine flight. All background.

FLIGHT 6/17/79 **SHIPMAN** **TIME: 1615-1650**

Routine flight. All background.

FLIGHT 6/18/79 **SHIPMAN** **TIME: 1800-1835**

Routine flight. All background.

FLIGHT 6/19/79 **SHIPMAN** **TIME: 1801-1821**

Routine flight. All background.

FLIGHT 6/20/79 **SHIPMAN** **TIME: 1730-1750**

Routine flight. All background.

FLIGHT 6/21/79 **SHIPMAN** **TIME: 1140-1200**

Routine flight. All background.

FLIGHT 6/22/79 **SHIPMAN** **TIME: 1625-1650**

Routine flight. All background.

FLIGHT 6/23/79 **SHIPMAN** **TIME: 1831-1850**

Routine flight. All background.

FLIGHT 6/24/79 **SHIPMAN** **TIME: 1915-1938**

Routine flight. All background.

FLIGHT 6/25/79 **SHIPMAN** **TIME: 2010-2030**

Routine flight. All background.

FLIGHT 6/26/79 **SHIPMAN** **TIME: 1730-1750**

Routine flight. All background.

FLIGHT 6/27/79 **SHIPMAN** **TIME: 1732-1804**

Routine flight. All background.

FLIGHT 6/28/79 **SHIPMAN** **TIME: 1725-1745**

Routine flight. All background.

FLIGHT 6/29/79 **SHIPMAN** **TIME: 1340-1407**

Routine flight. All background.

FLIGHT 6/30/79 **SHIPMAN** **TIME: 1150-1230**

Routine flight. All background.

FLIGHT 7/1/79 **SHIPMAN** **TIME: 1210-1250**

Routine flight. All background.

FLIGHT 7/2/79 **SHIPMAN** **TIME: 1425-1442**

Routine flight. All background.

FLIGHT 7/3/79 **SHIPMAN** **TIME: 2055-2120**

Routine flight. All background.

FLIGHT 7/4/79

No flights, bad weather.

FLIGHT 7/5/79 **SHIPMAN** **TIME: 1201-1225**

Routine flight. All background.

APPENDIX C

NBS CALIBRATION OF SURVEY METERS

DS: 7338/79
DB: 787:122-126
31 May 1979

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

NATIONAL BUREAU OF STANDARDS REPORT OF TEST

of

Two Radiation Survey Instruments

for

EG&G, Inc.
P.O. Box 16108
Suitland, MD 20023

Submitted on

25 May 1979

The two survey instruments were submitted for tests to determine the dependence of the instruments' readings on the energy of the incident radiation. The radiation spectra used for the tests are cesium-137 gamma rays and heavily filtered x-ray beams produced by constant potentials on the x-ray tube. The x-ray beams are characterized by their effective energies which are determined from the initial slopes of attenuation curves for the heavily filtered conditions. In most cases for these tests it was necessary to add more filtration to the standard filter to achieve instrument readings which were on scale. The extra filtration will increase the x-ray effective energies somewhat over the reference values, but the differences are believed to be insignificant of the purposes of these tests.

The instruments are identified as follows:

(1) Reactor Control Division
Elliott Automation Nucleonics Ltd.
Lewisham, London, Great Britain
Ratemeter
Scintillation Gamma
Type 1597A, Ser. No. 384
A.E.R.E. Cat No. 3-7/14958
EG&G P/N 204595

(2) Ludlum
Measurements Inc.
Sweetwater, Texas
Model 3
Geiger Counter
3857

Instrument No. 1 has a crystal-photomultiplier assembly parallel to and at the bottom of the case with the crystal at the front under the meter. Full scale reading for the ×1 multiplier is 30 μR/h. There are switch positions for ×10 and ×100 multipliers. For these tests the radiation beams were incident normal to the bottom of the instrument with the reference point the center of the crystal.

Instrument No. 2 has a Geiger-Muller tube as the detector and the probe has a side window. Full-scale reading for the ×1 multiplier is 2 mR/h. There are switch positions for ×0.1, ×10 and ×100 multipliers. The fast-slow time constant switch was in the slow position for all readings and sufficient time was allowed to determine the average reading. The radiation beams were incident normal to the axis of the G-M tube and readings were taken with the window open and closed.

The x-ray beams were standardized by using an Exradin Mod. A-6 air-equivalent ionization chamber. This chamber has a nominal air volume of 800 cm^3 and has been calibrated against the standard free-air ionization chamber for x-radiation generated for the standard heavy-filter conditions. The additional filtration required to reduce the standard exposure rates to the low values required for this test will not affect significantly the calibration data for the A-6 chamber. The A-6 chamber has also been calibrated in a standard cesium-137 gamma-ray beam.

The results of the tests are given in Table 1 in terms of instrument response, which is the quotient of the instrument reading and the x- or gamma-ray exposure rate.

A rough estimate of the statistical uncertainty for these measurements, in terms of the percent standard deviation for each exposure rate, is given in Table 2.

Table 1. Energy Dependence of Two Radiation Survey Instruments

Radiation Conditions			(1) Scintillation Detector			(2) G.M. Detector				
							Probe Window Open		Probe Window Closed	
Fdy constant potential or -ray source y or nuclide	Effective energy (keV)	Exposure rate X (mR/h)	Full scale reading (mR/h)	Reading Y (mR/h)	Response Y/X	Full scale reading (mR/h)	Reading Y (mR/h)	Response Y/X	Reading Y (mR/h)	Response Y/X
50	38	0.29	3.0	1.05	3.6	-	-	-	-	-
		18.7	3.0	o.s.*	-	20	o.s.	>1.1	1.1	0.06
		18.7	3.0	o.s.	-	200	41	2.2	-	-
		51.3	3.0	o.s.	-	20	o.s.	-	2.2	0.04
		51.3	-	-	-	200	90	1.8	-	-
100	70	0.82	3.0	o.s.	>3.66	2.0	o.s.	>2.44	o.s.	-
		0.82	-	-	-	20	4.5	5.5	2.3	2.8
		6.5	-	-	-	20	-	-	15.5	2.4
		9.3	-	-	-	20	o.s.	>2.15	o.s.	>2.15
		9.3	-	-	-	200	34	3.7	14	1.5
150	117	0.34	3.0	2.3	6.8	2.0	1.5	4.4	1.1	3.2
		1.1	-	-	-	20	4.0	3.6	3.0	2.7
		5.9	-	-	-	20	o.s.	>3.39	16	2.7
250	210	0.47	3.0	1.5	3.2	2.0	1.3	2.8	1.0	2.1
		5.7	-	-	-	20	10	1.8	9	1.6
		13	-	-	-	20	o.s.	>1.54	20	1.5
		13	-	-	-	200	16	1.2	13	1.0
^{137}Cs	660	5.2	3.0	2.7	0.52	20	4.5	0.87	4.3	0.83

*o.s. means the instrument reads off scale.

Table 2	
$\dot{X}$ (mR/h)	Uncertainty (%)
0.29	22
0.34	22
0.47	14
0.82	12
1.1	10
5.9	2
6.5	2
9.3	1.3
12.9	1.3
18.7	0.6
51.3	0.2

Measurements supervised by T. P. Loftus
(301) 921-2361.

Report approved by R. Loevinger

For the Director
by

Lewis V. Spencer
Acting Chief, Radiation Physics Division
Center for Radiation Research
National Measurement Laboratory

APPENDIX D

EXPOSURE RATE LEVEL SUMMARY

Table D-1. Flight Data Summary
(corrected for instrument calibration)*

Date	Time	Bearing From Plant (0°=North)	Distance (Miles)	Altitude (Feet)	Maximum Exposure Rate* (mR/h)
3/29/79	1600-1700	180°	0.2	500	5.0
		180°	0.5	500	0.2
	2230-2330	310°	0.5	500	0.2
3/30/79	1030-1130	135°	1	300	0.5
		225°	0.25	300	15.0
	1600-1800	280°	1	300	4.0
			1.5	300	4.0
			2	300	4.0
			2.5	300	4.0
			3	300	4.0
			3.5	300	2.0
			5	300	1.0
	2130-2230	330°	1	500	0.2
				1000	0.2
3/31/79	0015-0105	20°	1	500	0.5
	0300-0400	60°	1	500	0.8
				1000	0.4
	0600-0715	50°	1	500	1.0
				1000	0.4
	0900-1000	45°	1	500	2.0
				1000	0.2
			2	500	2.0
			3	500	1.0
			10	500	0.5
			22	500	0.05
	1215-1330	45°	1	500	0.8
			3	300	0.8
			10	1800	0.1
	1520-1540	125°	1	500	2.0
			3	500	0.5
	1843-1945	112°	1	500	1.0
			3	500	2.0
			8	500	0.5
	2100-2145	60°	1	500	0.4
		80°	3	500	0.5
		72.5°	15	500	0.08
		75°	10	500	0.08
4/1/79	0030-0100	105°	1	500	0.5
			3	500	0.03
	0155-0245	85°	1	500	0.5
		90°	2	500	1.0
		90°	4	500	0.05
	0600-0700	120°	1	500	2.0

*Raw exposure rate data as reported in flight notes have been divided by a factor of 2, based upon instrument calibrations performed by the National Bureau of Standards. The uncertainties in these corrected exposure numbers are estimated at ±50%.

Table D-1. Flight Data Summary (continued)
(corrected for instrument calibration)*

Date	Time	Bearing From Plant (0°= North)	Distance (Miles)	Altitude (Feet)	Maximum Exposure Rate* (mR/h)
		150°	3	500	0.3
	0900-0940	155°	1	500	2.0
		155°	3	500	0.2
		155°	10	500	0.1
	1300-1346	185°	1	500	0.5
		185°	3	500	0.2
	1408-1435	160°	1	500	2.0
	1515-1555	155°	1	500	2.0
	1800-1900	235°	1	500	0.2
		250°	3	500	0.05
	2110-2120	290°	0.75	500	0.05
4/2/79	0300-0400	290°	1	500	0.8
		290°	2	500	0.2
	0600-0615	315°	1	500	0.8
	0905-1005	150°	1	500	0.4
		155°	3	500	0.2
		155°	5	500	0.2
		155°	7	500	0.2
4/3/79	1200-1245	135°	1	500	1.0
		135°	3	200	0.6
		135°	7	700	0.2
	1500-1600	110°	0.5	500	1.0
		110°	3	200	0.2
		110°	6	150	0.2
	1815-1900	170°	1	500	1.0
		170°	3	500	0.2
		170°	4	500	0.5
		170°	6	500	0.1
	2100-2145	160°	10	500	0.3
		170°	6	500	0.3
		175°	3	500	0.3
		180°	1	500	0.2
4/4/79	0000-0100	200°	0.5	500	0.4
		220°	3	500	0.2
		220°	6	500	0.2
		235°	1	500	0.6
	0300-0330	210°	1	500	0.2
		135°	3	500	0.1
	0600-0640	225°	1	500	0.6
			3	500	0.2
		250°	10	500	0.1
	0900-0945	270°	1	500	0.5
	1200-1230	275°	1	500	0.4

* Raw exposure rate data as reported in flight notes have been divided by a factor of 2, based upon instrument calibrations performed by the National Bureau of Standards. The uncertainties in these corrected exposure numbers are estimated at ±50%.

Table D-1. Flight Data Summary (continued)
(corrected for instrument calibration)*

Date	Time	Bearing From Plant (0°= North)	Distance (Miles)	Altitude (Feet)	Maximum Exposure Rate* (mR/h)
4/5/79	0600-0645	60°	6	0	0.1
		60°	6	200	0.2
		60°	6	300	0.2
		60°	6	350	0.2
		60°	6	500	0.1
		70°	1	500	0.2
	0950-1040	125°	1	500	0.2
		125°	3	200	0.08
		125°	3	500	0.03
		125°	3	800	0.06
		125°	10	200	0.01
		125°	10	500	0.03
		125°	10	800	0.02
	1223-1327	115°	1	500	0.05
		115°	1	300	0.05
		115°	2	300	0.05
		115°	5	300	0.03
		115°	7	300	0.03
		115°	10	300	0.01
		115°	11	300	0.01
		115°	15	300	0.01
	1515-1615	130°	1	500	0.05
	2120-2150	40°	1	500	0.03
		40°	3	500	0.01
4/6/79	0600-0710	95°	1	500	0.08
	1810-1845	130°	1	500	0.03
		130°	3	500	0.01
	2055-2125	120°	1	500	0.03
		120°	3	500	0.03
4/7/79	0600-0645	130°	1	500	0.02
		130°	3	500	0.02
		130°	10	500	0.01
	1030-1100	135°	1	500	0.03
		125°	3	800	0.008
		125°	10	500	0.005
	1805-1845	135°	3	500	0.008
		135°	6	500	0.005
		145°	1	500	0.03
	2255-2335	150°	1	380	0.05
		160°	3	500	0.02
		160°	3	1000	0.08
	2350-2450	180°	0.5	500	0.5
4/8/79	0620-0700	190°	2.5	500	0.01

* Raw exposure rate data as reported in flight notes have been divided by a factor of 2, based upon instrument calibrations performed by the National Bureau of Standards. The uncertainties in these corrected exposure numbers are estimated at ±50%.

Table D-1. Flight Data Summary (continued)
(corrected for instrument calibration)*

Date	Time	Bearing From Plant (0°= North)	Distance (Miles)	Altitude (Feet)	Maximum Exposure Rate* (mR/h)
		200°	1	500	0.2
	0900-0945	165°	3	500	0.007
		170°	1	500	0.02
	1805-1830	275°	1	500	0.03
		275°	3	500	0.2
		275°	6	500	0.008
4/9/79	1238-1308	250°	1	500	1.0
	1805-1848	95°	3	500	0.03
		95°	3	1000	0.01
		100°	6	500	0.06
		105°	4	500	0.03
		120°	1	500	0.5
4/10/79	0627-0800	140°	7	500	0.003
			1	200	0.05
		140°	1	1000	0.01
		140°	2	500	0.03
		140°	7	500	0.003
	1833-1913	120°	1	500	0.008
		120°	2	200	0.005
		135°	3	200	0.004
		135°	5	200	0.005
4/12/79	0938-1016	270°	3	700	0.004
		300°	1	100	0.001
		300°	1	300	0.004
		300°	1	500	0.005
		300°	1	1000	0.001
		315°	1	500	0.01
4/13/79	2252-2335	270°	0.5	500	0.003
4/14/79	1138-1221	170°	0.25	270	0.02
	2152-2350	60°	0.5	300	0.01
		80°	1	750	0.04
		330°	0.25	500	0.01
		330°	0.50	300	0.01
		350°	1	300	0.01
		355°	4	500	0.01
4/15/79	1720-1815	120°	0.5	300	0.007
		120°	1	500	0.003
		120°	3	500	0.002
4/19/79	1805-1855	160°	0.25	500	0.002
4/20/79	0821-0912	80°	0.25	350	0.004
4/27/79	1345-1540	325°	0.5	500	0.05
	1545-1630	325°	0.5	500	0.05
	1720-1750	325°	1	500	0.01

* Raw exposure rate data as reported in flight notes have been divided by a factor of 2, based upon instrument calibrations performed by the National Bureau of Standards. The uncertainties in these corrected exposure numbers are estimated at ±50%.

Table D-1. Flight Data Summary (concluded)
(corrected for instrument calibration)*

Date	Time	Bearing From Plant (0°=North)	Distance (Miles)	Altitude (Feet)	Maximum Exposure Rate* (mR/h)
5/1/79	2000-2057	160°	3	500	0.005
		160°	0.25	500	0.01
		160°	0.5	500	0.09
5/3/79	1753-1841	330°	1.5	300	0.008
5/4/79	2139-2157	150°	0.5	500	0.01
		150°	1	500	0.008

*Raw exposure rate data as reported in flight notes have been divided by a factor of 2, based upon instrument calibrations performed by the National Bureau of Standards. The uncertainties in these corrected exposure numbers are estimated at ±50%.

APPENDIX E

ARAC CALCULATIONS WITH COVER LETTER

LAWRENCE LIVERMORE LABORATORY

An Equal Opportunity Employer

Mr. R. H. Beers
Assistant Operations Manager
EG&G
Aerial Measurement Dept.
Box 16108
Suitland, MD 20023

July 12, 1979

Dear Mr. Beers:

We have examined the ARAC computer code output that coincides with the EG&G Three-Mile-Island (TMI) flights of March 31 and April 1, 1979. Copies of that output are attached.

The seemingly "anomalous" conditions referred to in your letter of July 6, 1979 to Mr. L. Joe Deal should not be unexpected. This is not readily apparent from the model calculations at a 2-5 km resolution shown on the attached ouput (Atch 1); however, at the greater resolution the spatial variation close in would be quite apparent and expected. A more dramatic example of the spatial variation, both in the horizontal and vertical, is evident in attachments two through five. These examples (instantaneous concentration at 2, 3, 65, and 66m respectively) coincide with the flight on April 1, at 1515-1555 EST (2015 GMT-2055 GMT). Attachment six is output from the PATRIC model which assumes a flat terrain in the calculations. This also shows a concentration contour pattern where the concentration downstream increases then decreases. One should expect this behaviour anytime measurements are made downwind and considerably above the release point. This particular output was from a "first-12-hours" assessment of the TMI incident that was recently accomplished.

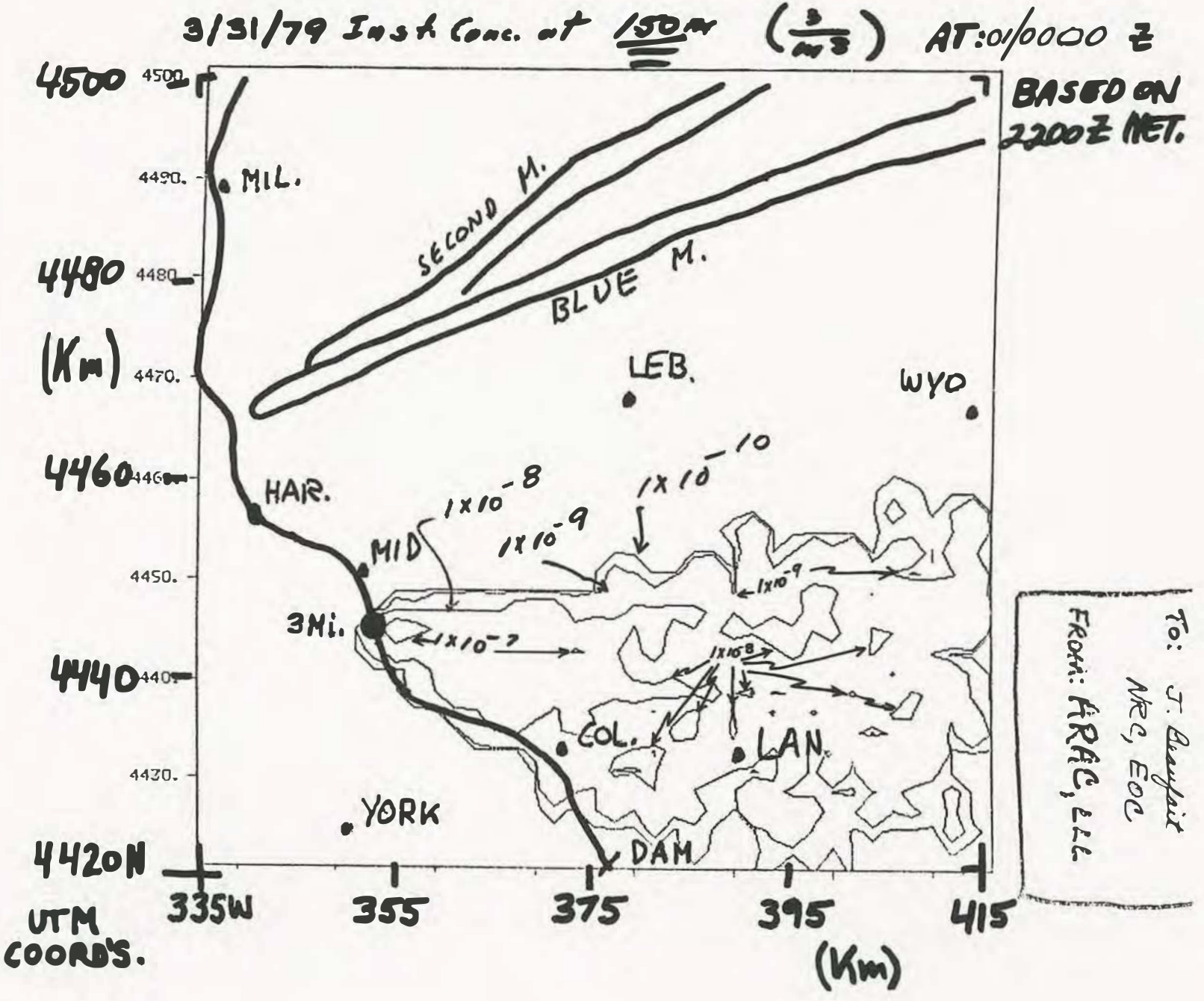
We are in agreement with you that the concentration patterns indicated by the airborne sample readings are reasonable. The combination of spatial variations, due to meteorological and/or topographical conditions, with those of a non-uniform source term and different source height and sampling height should lead one to expect non-uniform concentration patterns that deviate from idealized smooth contours.

Sincerely yours,

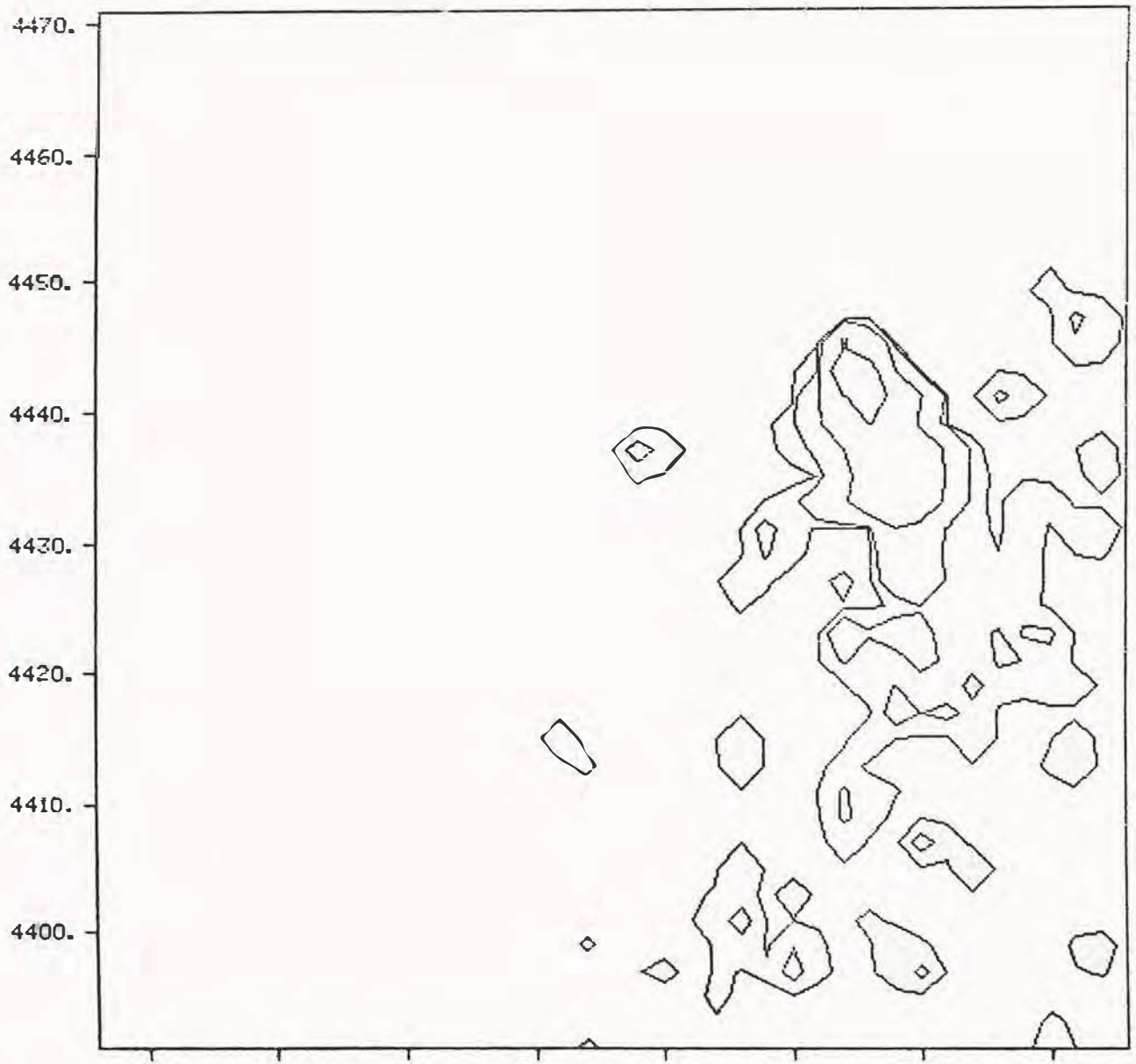
George D. Greenly, Jr.
Atmospheric Physicist
Atmospheric and Geophysical
Sciences Division
Physics Department

GDG:clm

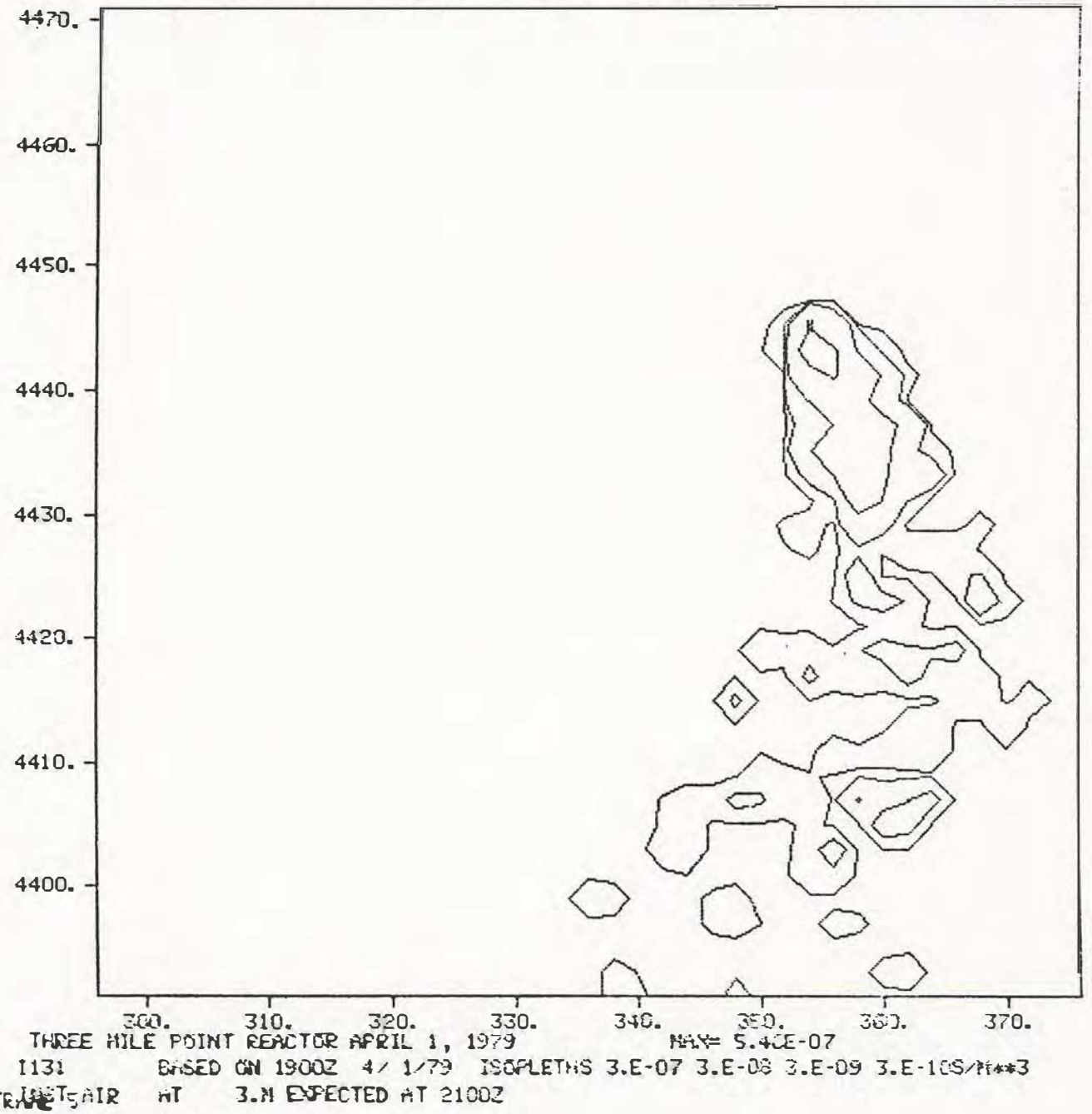
Enclosures (6)


3/31/79 Inst Conc. at 150m (Ci/m³) AT: 01/0000 Z
BASED ON 2200Z MET.
4500
4490.
4480
4480.
(Km)
4470.
4460
4460.
4450.
4440
4440.
4430.
4420N
MIL.
SECOND M.
BLUE M.
LEB.
WYO
HAR.
MID
3Mi.
YORK
COL.
LAN
DAM
1x10⁻⁸
1x10⁻⁹
1x10⁻¹⁰
1x10⁻⁹
1x10⁻⁷
1x10⁻⁸
335W
355
375
395
415
(Km)
UTM COORD'S.
To: J. Bradfair NRC, EOC
From: ARAC, LLL

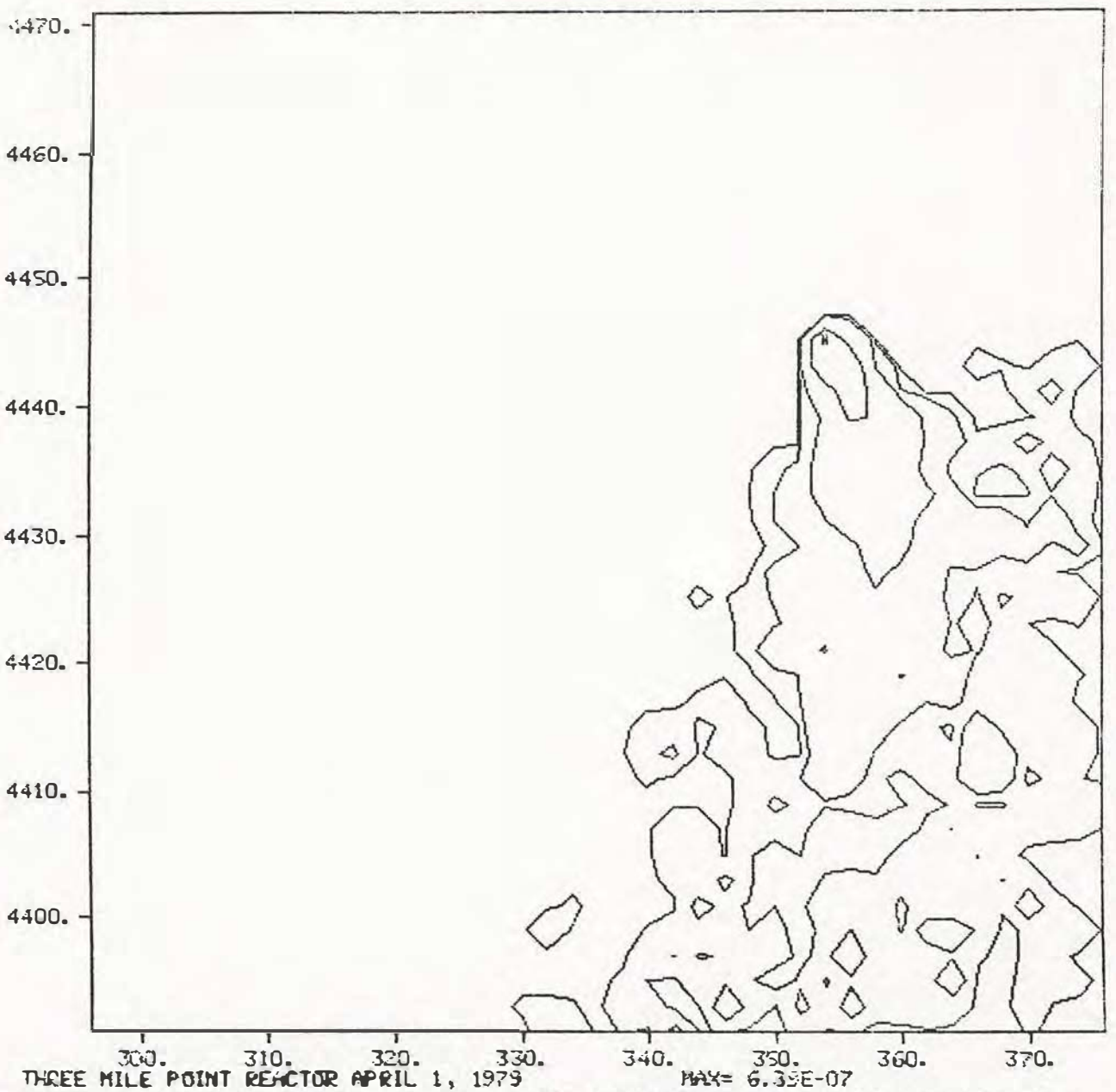
ATCH 1


4470.
4460.
4450.
4440.
4430.
4420.
4410.
4400.
300.
310.
320.
330.
340.
350.
360.
370.
THREE MILE POINT REACTOR APRIL 1, 1979
MAX= 6.39E-07
XE133 BASED ON 1900Z 4/ 1/79 ISOPLETHS 3.E-07 3.E-08 3.E-09 3.E-10S/M**3
FROM 2AIR AT 2.M EXPECTED AT 2100Z

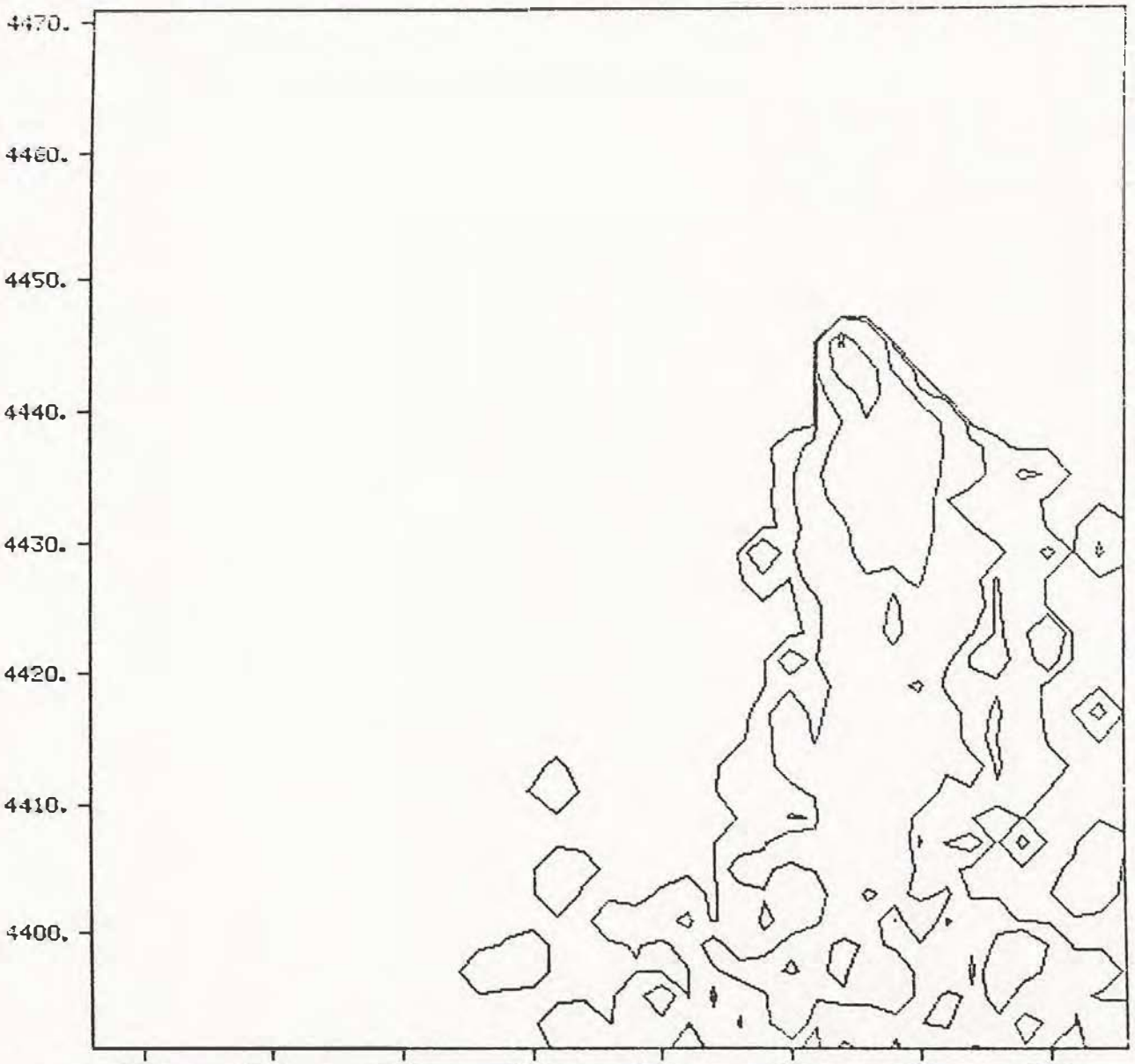
ATCH 2


4470.
4460.
4450.
4440.
4430.
4420.
4410.
4400.
300.
310.
320.
330.
340.
350.
360.
370.
THREE MILE POINT REACTOR APRIL 1, 1979
MAX= 5.4CE-07
1131
BASED ON 1900Z 4/ 1/79 ISOPLETHS 3.E-07 3.E-08 3.E-09 3.E-10S/M**3
AIR HT 3.M EXPECTED AT 2100Z

ATCH 3


4470.
4460.
4450.
4440.
4430.
4420.
4410.
4400.
300.
310.
320.
330.
340.
350.
360.
370.
THREE MILE POINT REACTOR APRIL 1, 1979
MAX= 6.35E-07
XE133 BASED ON 1900Z 4/ 1/79 ISOPLETHS 3.E-07 3.E-08 3.E-09 3.E-10S/M**3
AIR AT 65.M EXPECTED AT 2100Z

ATCH 4

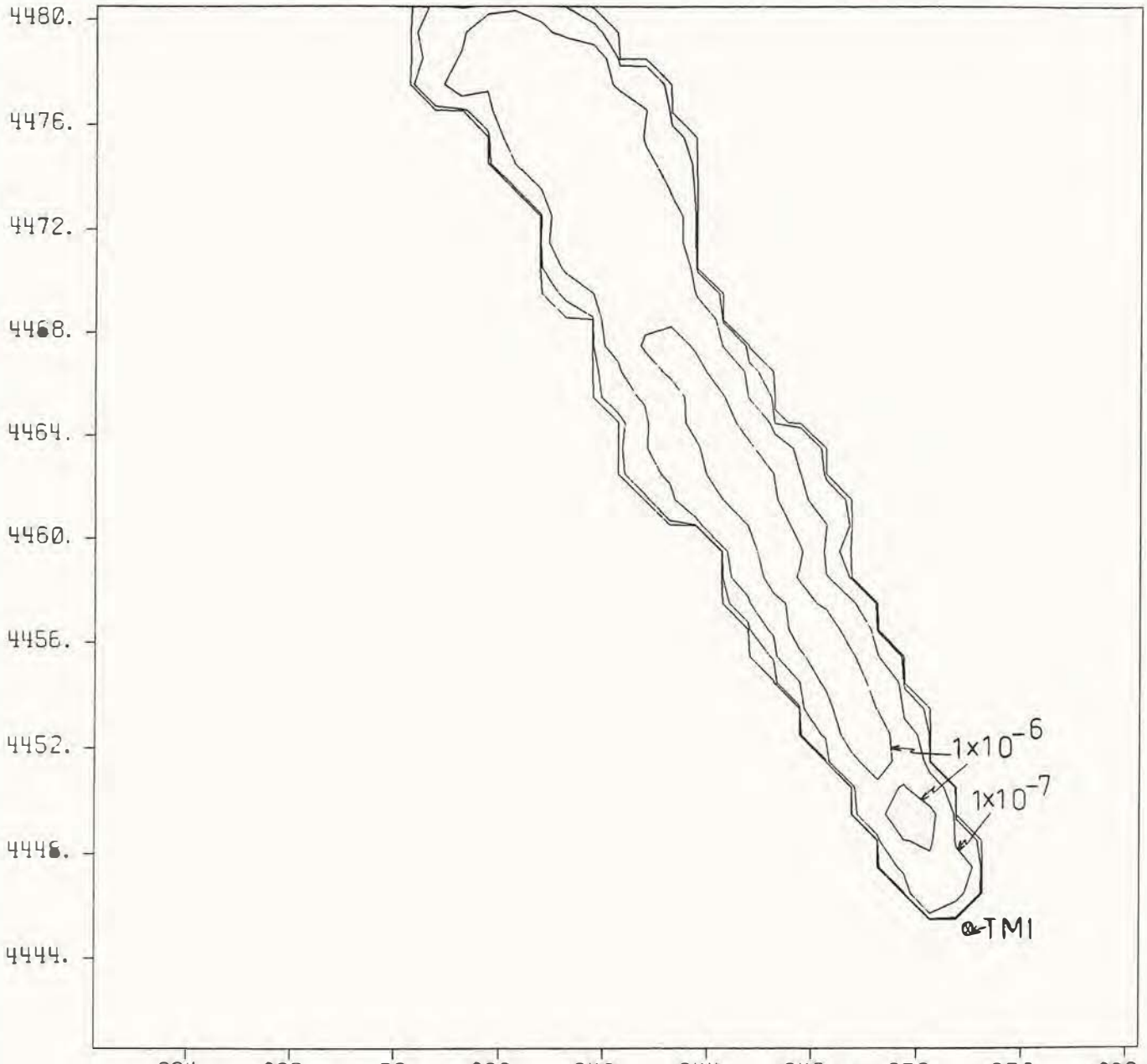


THREE MILE POINT REACTOR APRIL 1, 1379 MAX= 4.53E-07

I131 BASED ON 1900Z 4/ 1/79 ISOPLETHS 3.E-07 3.E-08 3.E-09 3.E-10S/M**3

FROM WIND AIR AT 66.M EXPECTED AT 2100Z

ATCH 5



THREE MILE ISLAND ASSESSMENT. 28 MARCH1979 MAX= 2.29E-06
XE133 BASED ON 2300Z 3/28/79 ISOPLETHS 1.E-06 1.E-07 1.E-08 1.E-09S/M**3
INST AIR AT 150.M EXPECTED AT 0Z

APPENDIX F

AIRBORNE MEASUREMENTS OF KRYPTON GAS DURING PURGING OPERATIONS

The Aerial Measuring System (AMS) was deployed June 25 and 26, 1980 to support EPA, NRC and ARAC during the scheduled purging of radioactive krypton gas from the TMI No. 2 containment vessel.

In order to determine the accuracy of plume forecasting data, it was deemed necessary to measure the concentration in the plume during the venting process. These measurements were to serve as a check of the predictive capability of ARAC/EPA, both of whom made calculations for varying release conditions.

The BO-105 helicopter, equipped with sensitive gamma radiation detection instruments and data acquisition equipment, was stationed at the Capital City Airport near Harrisburg, Pennsylvania, along with eight AMS personnel and associated data reduction equipment.

On request, the helicopter flew six missions. Each mission was initiated by a series of circular flights in the immediate proximity of the release site.

Once the plume was identified, the helicopter flew outward from the release site in the direction of the plume and then flew several legs, at varying altitudes, normal to the center line radial of the plume as the ^{85}Kr was detected.

A real-time strip chart indicating the count rate in the ^{85}Kr photo peak window was observed by the onboard scientist. The isotope ^{85}Kr is primarily a beta emitter, however, 4 out of the 1000 disintegrations produce a 0.51 gamma ray. After the plume had been located and defined in a particular sector, the extent of the plume at varying altitudes and distances from the point of release was measured. The aircraft tracked the plume to the limit of detectability of the airborne detection system and further defined the plume shape and size.

Following each flight, a computer analysis of the radiation data was completed. The computer converted the collected count rate data into concentrations per unit volume. The information was immediately transmitted to the ARAC/EPA command post for comparison to predictive calculations.

A summary of the data collected during the flights at TMI on June 29 through July 2, 1980 is shown in Table F-1.

Table F-1. Summary of Aerial Survey Results for the ^{85}Kr Purge

Date/Time	Distance (Miles)	Altitude (Feet)	Sector	Maximum Concentration of ^{85}Kr (Pci/l)
6/29/80				
Take-off Time: 15:15	2.5	200	2	20
	0.5	200	2	18
	0.5	750	2	17
	0.5	500	2	78
	0.5	300	2	53
	0.5	200	2	85
6/30/80				
Take-off Time: 10:50	0.75	200	7	31
	0.75	300	6	56
	0.75	400	7	48
	0.75	500	7	21
	0.75	750	7	24
	1.50	200	7	20
6/30/80				
Take-off Time: 17:50	0.90	200	7	19
	0.90	300	7	46
	0.90	400	7	52
	0.90	500	7	51
	0.90	750	7	28
	1.90	300	6	26
	2.5	400	5	29
	1.90	500	6	26
	1.90	750	6	21
7/1/80				
Take-off Time: 10:15	0.5	750	5	126
	0.5	500	6	98
	0.5	400	4	91
	0.5	300	6	88
	0.5	200	6	23
	0.9	750	6	26
	1.2	500	5	34
	0.9	400	7	31
	1.2	300	5	29
	1.2	200	5	20
	2.2	750	5	20
	2.2	500	5/6	21
	2.2	400	5/6	20
	1.8	300	6	21
	2.2	200	5/6	18
	0.25	1500	7	11
7/1/80				
Take-off Time: 17:22	0.25	200	5	25
	0.25	300	5	181
	0.25	400	5	312
	0.25	500	2/3	167
	0.25	400	2/3	218
	0.25	300	2/3	344

Table F-1. Summary of Aerial Survey Results for the ^{85}Kr Purge (concluded)				
Date/Time	Distance (Miles)	Altitude (Feet)	Sector	Maximum Concentration of ^{85}Kr (Pci/l)
7/1/80				
Take-off Time: 17:22	0.25	200	2/3	496
(continued)	1.0	500	3	94
	1.0	400	3	99
	1.0	300	2	121
	1.0	200	3	133
	2.0	500	2/3	46
	2.0	400	3/4	48
	2.0	300	3	48
	2.0	200	3	32
	2.0	750	2	38
	1.0	750	2	102
7/2/80				
Take-off Time: 06:00	0.25	1000	1/2	18
	0.25	750	1/2	144
	0.25	500	1/2	172
	0.25	400	1/2	318
	0.25	300	1/2	171
	0.25	200	1/2	249
	1.00	750	2/3	47
	1.00	500	2/3	77
	1.00	400	2/3	65
	1.00	300	2/3	48
	1.00	200	2/3	29
	2.00	750	2	18
	2.00	500	3	46
	2.00	400	2/3	15
	2.00	300	2	20
	2.00	200	3	16
	2.00	1000	3	20

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MIDDLETOWN, PENNSYLVANIA
EGG-10282-1009
DATE OF SURVEY: MARCH - JUNE 1979
DATE OF REPORT: DECEMBER 1984