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ENVIRONMENTAL MONITORING SYSTEM FOR NUCLEAR TESTS

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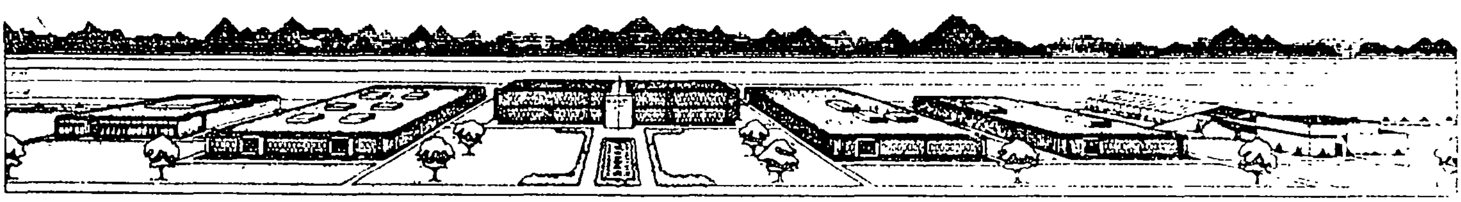

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INTRODUCTION

Following history's first nuclear explosive test in 1945 in the southwestern part of the United States, further testing on the North American mainland was resumed in 1951 at a relatively remote test area in the state of Nevada. Periodic testing has continued at this location, as well as several other experimental sites, until the present time (1). These tests have included experiments to investigate scientific and engineering applications of nuclear explosions as well as to develop nuclear weapons. Since 1963, all nuclear explosive tests conducted by the United States have been detonated underground. These tests have been designed to prevent radioactivity produced by the explosions from escaping to the atmosphere, whereas several of the Plowshare engineering development explosions released predicted amounts of activity to the atmosphere.

In 1954, in accordance with a Memorandum of Understanding with the U. S. Atomic Energy Commission, the U. S. Public Health Service assumed the responsibility for conducting the radiological monitoring program in the public area around the test sites (2). The Southwestern Radiological Health Laboratory* was established in Las Vegas, Nevada to provide radiation

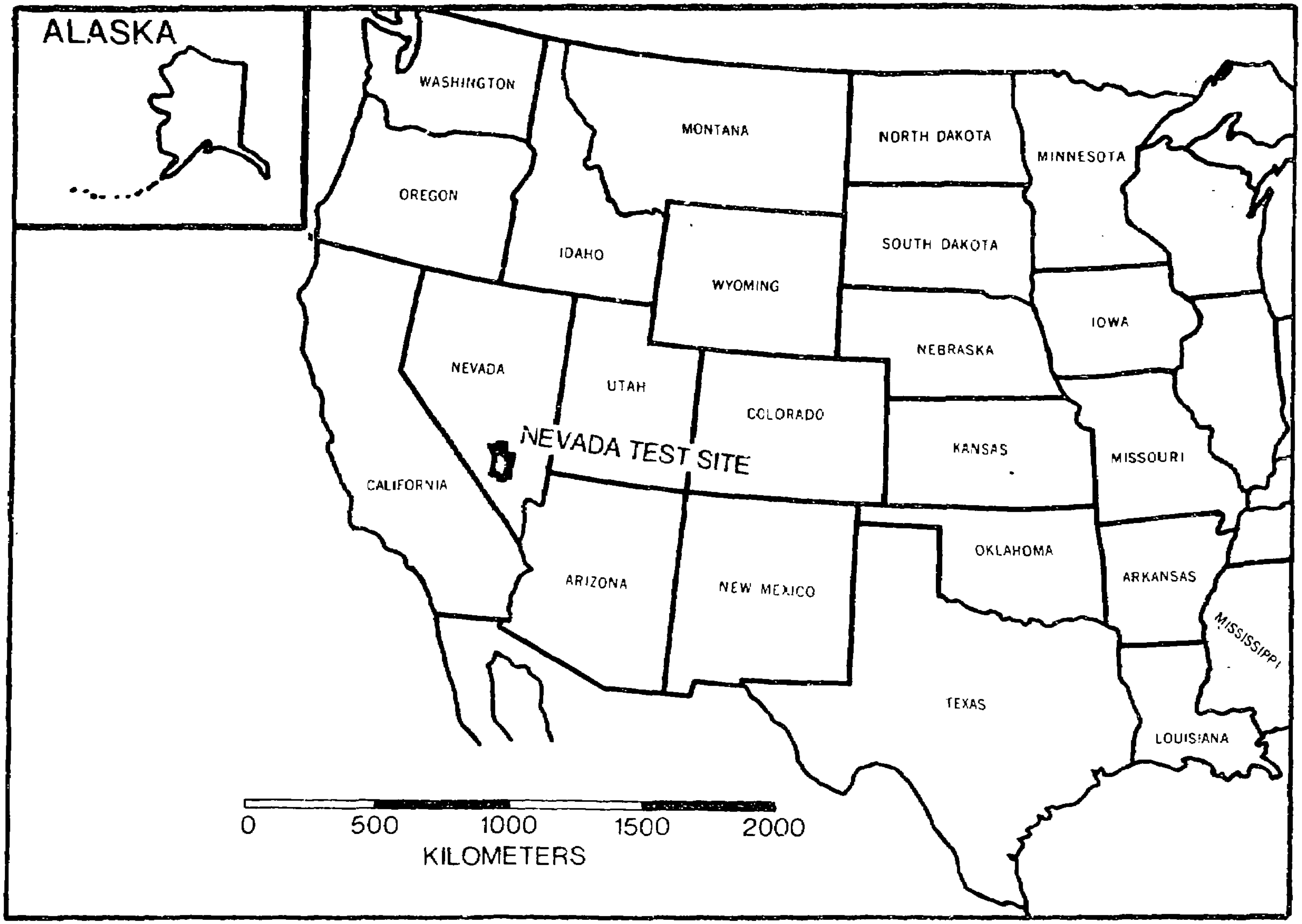
*Now the Western Environmental Research Laboratory, following its transfer from the U. S. Public Health Service to the Environmental Protection Agency on December 2, 1970.

monitoring personnel and analytical facilities to perform radiological analyses. As the science of radiological monitoring developed, these basic laboratory capabilities evolved into a comprehensive environmental monitoring system for the nuclear tests. Advanced analytical techniques were continually developed and applied, and computer data processing was instituted in the early 1960's to handle the large volume of information produced by the monitoring programs. Concurrently, an aerial monitoring capability was added to supplement the ground monitoring program. This aspect of the overall monitoring system, in particular, required development of unique instrumentation and sampling equipment. A radiological research program was also added in the early 1960's to develop information specifically related to environmental and public health problems and questions associated with the nuclear testing activities, whereas physicians and veterinarians were added to the staff to provide expertise in responding to medical (3) and veterinary inquiries relating to the testing programs.

OBJECTIVES

The primary objective of this comprehensive monitoring system is to assure public safety (4). In accomplishing this, the potential long-term hazards of radioactive releases from the test locations are considered as well as the potential immediate hazards resulting from an accidental or planned release of radioactivity from nuclear tests. Transient levels of radioactivity significantly above background are fully documented, and long-term levels that may be only slightly above background are similarly documented and investigated. This documentation includes developing dosimetry records for residents and populated areas, followed by careful assessment of these data in relation to applicable exposure guides and standards. Additionally, the recent emphasis on consideration of any environmental impact has required even more comprehensive documentation to determine any radiological contribution to the environment as well as determine direct effects to the population. Another, equally important, objective involves providing accurate information to the public so they may know the effects (or lack of effects) on themselves and their environment.

The need for a "rapid" environmental monitoring system in this particular program is based on the need to respond to potentially large releases of radioactivity that can move rapidly across an extensive geographical area affecting a segment of the population. The monitoring program must therefore cover a large area, as shown in Figure 1. Although a radioactive release from the primary nuclear explosive test site in the United States (the Nevada Test Site near Las Vegas, Nevada in the southwestern U. S.) may travel 50 or 60 kilometers before reaching the site boundary, the public area to be monitored may extend another 2,500 kilometers or more from the site. Although the nuclear tests conducted by the United States during the last decade have been designed to minimize the possibility of a radioactive release to the greatest extent possible (or to minimize the planned releases involved in certain engineering experiments), the Laboratory must be prepared to rapidly assess the situation and take necessary action on a timely basis should releases to the environment occur. Even if a release occurs that does not represent a severe hazard to the population, the rapid system approach has been applied in order to follow the philosophy that any radioactive exposures



WESTERN STATES MONITORED FOR U. S. NUCLEAR TESTING PROGRAMS

FIGURE 1

to the population should be minimized as much as practicable. This approach is followed for special test sites (5,6) as well as for testing programs conducted at the Nevada Test Site. Special tests for engineering applications of nuclear explosives and seismic studies have been conducted at other sites in the states of Nevada, Colorado, New Mexico, and Mississippi, and on Amchitka Island in Alaska.

PROCEDURES

Although pertinent predictions are made prior to each test, if a radioactive release from a nuclear test occurs, the radiation intensity, as well as the direction and speed of the debris cloud, must be determined quickly so its trajectory and effects can be predicted. This requires an aerial tracking and monitoring capability to evaluate the nature of the release and the aerial trajectory so that ground level monitoring can be performed to determine exposures to the population. The information collected must then be transmitted to a control center for rapid evaluation. Once trajectory and effects predictions are made, using real-time data, instructions for any indicated protective measures are relayed quickly by radio to field personnel for implementation (7,8). They are prepared to evacuate residents, close roads, cover or substitute livestock feeds, and take any other practicable protective measure that may be required to minimize exposures. Concurrently, the radiological and distribution parameters of the release material are monitored on a continuous basis to keep abreast of changes and to document radiation levels and exposures.

This documentation program then becomes the most extensive phase of the monitoring system. Protective measures may be instituted for some time, during which documentation monitoring is continued to ascertain when the measures are no longer required. However, subsequent documentation monitoring continues for an extended period to assure complete evaluation of all exposure parameters, as well as to gather data for prediction verification and use in designing prediction models that may be applied to other releases.

Several basic techniques are employed to provide a rapid response system. These include well equipped mobile monitoring teams, real-time readout instrumentation, use of telemetry, automatic recorder and sampling procedures, and sample analysis in the field. Rapid transport of samples to the Laboratory, automated laboratory analyses and computerized data processing are also major factors in the system. The analytical and data processing capabilities are particularly important since these facilities must handle not only a variety of environmental samples collected by ground and aerial monitoring teams, but also samples from several air and milk surveillance network stations located around the western two-thirds of the United States.

MONITORING PROCEDURES

Special instrumentation techniques are applied in both the aerial and the ground monitoring efforts conducted by the laboratory. The monitoring aircraft have been modified to serve as "flying platforms" for tracking and sampling instrumentation. In addition to strengthened airframes and installation of more powerful turbine engines to enable safe operation at low or high altitudes, the twin-engine, eight-passenger aircraft are equipped with several additional electrical systems to operate the variety of instrumentation carried in the aircraft. Special instrumentation ports and sampling probes have been installed in the aircraft hull, and all equipment is designed to facilitate rapid equipment changeout so different types of monitoring missions can be flown with a minimum ground time between missions. All equipment can be replaced quickly with seats to accommodate rapid movement of specialized personnel.

Output signals from the gross gamma radioactivity detection systems on the aircraft are recorded on a continuous chart recorder in the crew chief's instrument panel so standard navigation instrument data as well as Doppler radar navigation data can be combined with tracking data to obtain cloud dimension and trajectory information. Gross gamma data from instrument packages dropped by parachute and telemetered back to the aircraft can also be displayed on the chart recorder, providing real-time information on the vertical distribution of activity in the debris cloud. Counting instrumentation in the aircraft provides in-flight data on particulate activity concentrations and decay characteristics for samples collected in the cloud.

Airborne particulate samples can be collected sequentially or for extended periods using particulate filters. A system of electrostatic precipitator tubes collect particulate samples for radiochemical analysis, and activated charcoal cartridges are employed to collect reactive gases. Bulk air samples, which may first be passed through molecular sieve for tritium and carbon-14 recovery, are compressed into pressure cylinders for noble gas analysis at the laboratory. Cryogenic sampling systems using liquid nitrogen to cool low-temperature freeze traps are also used for noble gas sampling. These aerial sampling and tracking systems thereby provide early information on the type, concentration, distribution and trajectory of radioactivity, enabling timely positioning of ground monitoring teams in the downwind area to intercept and document activity and exposure levels in populated areas and activation of field environmental sampling stations.

The basic equipment item to enable ground monitoring teams to move quickly to a strategic location is a suitable vehicle. In must be able to traverse unimproved roads as well as highways, and provide carrying capacity for a variety of instruments and sampling equipment. Light trucks with covered cargo beds for equipment protection are used extensively, and are equipped with long-range two-way radios for communication with the aircraft and control center. The vehicles are also equipped with a special electrical circuit to charge storage batteries used to power portable sampling equipment.

Portable air samplers and radiation recorders are used so monitoring data can be collected at numerous locations, both populated and unpopulated, to obtain thorough documentation of activity levels and exposures in the area. This portable equipment supplements the network sampling stations and radiation monitoring stations operated on a continuous basis throughout the area. The battery powered units, rather than generator powered, are used to minimize weight and bulk as well as to provide greater reliability. Battery powered units also require less time for deployment and maintenance.

Once the debris cloud has passed, the residual fallout pattern must be assessed. Sampling and monitoring continue in the pattern area, which is defined by mobile scanning systems mounted in highway-vehicles. As the vehicle travels at highway speeds, the detection system output signals are plotted on a continuous recorder chart, driven by the vehicle's odometer drive system. The extent and intensity of the fallout pattern can thereby be mapped quickly to provide guidance on where further monitoring and sampling should be conducted. Water, soil, vegetation, livestock forage, milk, food crops and other environmental samples are collected from the area for analysis at the laboratory.

The time period between sample collection and analysis must also be minimized as much as possible. This objective has been met by scheduling field monitors to deliver samples to control points in the field, and then having sample couriers transport the samples to the laboratory. Even more rapid delivery to the laboratory is accomplished by using aircraft to transport the samples. Aircraft capable of operating from unimproved landing strips are required for this support

SAMPLE ANALYSIS AND DATA PROCESSING

Information that samples are scheduled for collection is transmitted to the laboratory by radio. If preliminary measurements by the sampling and tracking aircraft indicate a major release, preparations are made in the laboratory to screen personnel and samples to prevent laboratory contamination and to arrange the work schedule so that personnel will be available on a 24-hour basis. The first samples are delivered to the laboratory by aircraft and arrive within two hours of the time of release of radioactivity. Samples collected on the ground usually do not arrive until six to eight hours after the release.

Samples are delivered to a central sample control point, and information about the sample and the analyses requested are recorded on computer forms. A copy of the form goes directly to the computer facility which initiates the report generating process. Carbon copies of the form accompany each sample through the laboratory where analytical data are attached to or recorded on the form. The information is ultimately assembled in the computer room for calculation and reporting.

As most radionuclides produced by fission and activation in a nuclear test emit gamma rays, the first procedure performed on samples is gamma spectrum analysis. To count the large numbers of samples that may be collected (as many as 3000 samples in a month following a major release) ten identical gamma spectrometer systems are used. Five 400-channel analyzers, using two 10- by 10- centimeter detectors each, provide two hundred channels per detector. Measurements are made over the energy range of 0-2 MeV. and output data from these systems are punched on paper tape and printed by automatic typewriter.

Four standard counting geometries are used, depending on the type and size of sample counted. In addition, charcoal cartridges are counted directly on the detector for quantitative identification of reactive gaseous isotopes. Vegetation samples are counted directly in plastic bags for qualitative analysis.

The counting times used vary from 4 to 40 minutes depending on the type of sample, activity in the sample, and the sample load. The counting data generated on paper punch tape are converted onto cards by a computer program, and the sample information from the sample control card is key-punched onto cards which are merged with the gamma spectral data and entered into the computer for data analysis. Gamma spectra from calibration standards which have been previously counted in each geometry are stored in the computer for each counting system. For special radionuclides, for which no accurate standards are available, efficiency factors are determined by an energy-efficiency curve.

The gamma spectral data are analyzed by a simultaneous equation technique (9). Three separate reference files of data, each containing eight radionuclides, are maintained in the computer for solution of the simultaneous equation matrix. The eight nuclides are grouped according to the predominant half-lives of the nuclides, and the proper file is selected based on the particular situation and knowledge of the samples. The combination of eight nuclides can be specified and readily changed. The program calculates the activity of each nuclide specified in the file and reports the activity at the time of count and at the time of collection. If a nuclide or nuclides are determined to be absent by a statistical test against background, those nuclides are deleted from the matrix and the computer recalculates the concentrations with the new matrix.

On a routine basis, the calculated concentrations in a sample are available within 24 hours of the receipt of the sample. When necessary, such as during a release of radioactivity from the test site, a group of fifty samples can be logged in, counted, analyzed, and reported within six hours. As many as 200 samples can be analyzed and reported within 24 hours and results of samples received in the laboratory by 6:00 p.m. are available by midnight.

Measurement of gross radioactivity in air is an important aspect of the surveillance system. A highly automated counting system is utilized for both routine surveillance stations and for special samples collected following a detonation. Routine samples from one hundred air surveillance stations operating on a 24-hour basis are mailed to the laboratory by the volunteer station operators. Counting data are processed through a computer program which generates a daily report and selects those samples for gamma spectral analysis based on preset criteria. Whenever required to respond to a radioactive release, the station operators are notified by telephone to change filters at selected times or to insert charcoal cartridges into the sampling train.

Air filters collected by aircraft are first beta counted and then analyzed by gamma spectroscopy. These measurements are repeated on a schedule which varies from hourly at first to daily after several days and weekly after two weeks. Recounts may continue for several months to determine half-lives to be used with the gamma spectral data to identify all the radionuclides in the complex fission and activation product spectra. Portions of the samples are analyzed for strontium and plutonium isotopes (10) and charcoal cartridges are gamma counted to determine isotopes of iodine, xenon, and tellerium.

Electrostatic precipitator tubes from the aircraft air particulate sampling system are washed with solvents to remove all radioactivity which is put into solution prior to separation into chemical groups. The nuclides are then identified by a combination of chemical separations, gamma spectroscopy, beta counting, and solid state gamma counting. The analysis takes from three to seven days to complete. Air samples collected in pressurized bottles and cryogenic samplers receive special noble gas analyses (11). The data from these aircraft samples are used in conjunction with the in-flight measurements to determine the location and trajectory of the radioactive cloud, and to estimate the total inventory of radioactivity that was released.

The various analytical results are reviewed as soon as available and several decisions are made based on the results. These are:

a. The need for additional sampling the following day where results are positive.

b. The additional locations that should be sampled.

c. The necessary protective measures that should be taken if levels are significantly high.

d. The need to recount samples to determine the long-lived components after short-lived nuclides have decayed away and to determine half-lives of nuclides to confirm identification.

e. The need for additional analysis, e.g., if fresh fission products are found in milk, the samples are analyzed for strontium-89 and 90.

To assure the accuracy and precision of the analytical data, a quality control program is conducted (12). This program supplies calibration standards, provides calibration services, submits blind duplicates for analysis, and submits cross-check samples on a regular schedule. The Laboratory also participates in the World Health Organization cross-check program.

The several data generating programs produce a wide variety of report formats. Preliminary reports list only the sample identification and the analytical results. Weekly summaries are printed which describe the sample collection location and lists in chronological order all samples collected at a particular station and groups the data by specified geographical area. These computer generated reports list the data in a columnar format of sufficient clarity to be issued as part of a report available to the general public. The files can be corrected or updated as additional recounts and analyses are performed.

In addition to environmental sample analysis, bioassays are performed when individuals are suspected of having a body burden of internally deposited radionuclides. These individuals might be either laboratory employees who were exposed during monitoring operations, or members of the general public living in the off-site area. A whole body counter (13) at the laboratory and portable field units for whole body or thyroid counting are used to assess body burdens of gamma-emitting radionuclides. Biological samples, usually of urine or feces, are collected and analyzed for other radionuclides. All radionuclides determined in environmental samples can also be measured in bioassay samples.

ENVIRONMENTAL AND PUBLIC HEALTH EVALUATION

Data collected for a particular radioactive release are assembled to perform an environmental and public health evaluation (2). This evaluation requires the consideration of many parameters. These include:

a. Source Term

Quantity, type and form of the various radionuclides released to the environment.

b. Environmental Transport

Transport of radionuclides from the point of release to where they are or could be a source of exposure to the general population (atmospheric and water transport).

c. Ecological Transport

Transport through the ecological system to an individual, e.g., the milk-food chain.

d. Dose to Man

Calculation or determination of the resulting dose to man from the various radionuclides via inhalation, ingestion, and external exposure.

The Laboratory is primarily involved in each of these general areas but devotes most of its efforts to the last two factors.

The critical nuclides are identified by reviewing the radionuclides measured in the media which lead to radiation dose through inhalation and ingestion. Internal doses are then calculated using parameters and procedures outlined in FRC (Federal Radiation Council) and ICRP reports (7,14-18). The several assumptions made in these calculations are carefully examined to assure that they apply to the local situation. External exposures are determined from gamma rate recorder data and from thermoluminescent dosimeters issued to residents and placed at various locations in the area. These data are then used to provide isopleth maps for the particular release. If the release of activity is of sufficient magnitude to result in deposition of radioactivity in people that can be measured by bioassay whole body counting, these data are used to verify calculations based on environmental sampling.

Finally, a combination of these data is used to determine the total integrated doses to the off-site population that result from released radioactivity. These doses are compared to established Federal Radiation Council guides to evaluate the radiological impact of the release. Also, cumulative records of dose are maintained for reference and guidance in planning future activities.

A particular radiological situation can usually be adequately assessed with a reasonable amount of effort by determining the following:

a. critical receptor

b. critical radionuclides

c. critical environmental media and food chains

d. dose commitment

e. pertinent cumulative dose

In order to evaluate the long term implications of nuclear testing on people and their environment, surveillance is conducted on a continuing basis. Through this program trends in levels of long-lived radionuclides can be assessed and the impact of nuclear testing in terms of radiation exposure to humans can be continually evaluated.

SUMMARY

The extensive environmental monitoring system maintained by the Western Environmental Research Laboratory for nuclear testing programs in the United States is designed to produce comprehensive information and data on radioactive contamination and exposures as quickly as possible. This is accomplished through use of aircraft and mobile ground monitoring teams that can make radiation measurements and collect a variety of environmental samples, followed by specially designed laboratory analytical procedures and data processing to expedite data acquisition. The system can thereby provide rapid assessment of radioactive releases that may affect a large segment of the population within the western United States. The information is then used to evaluate both short-term and long-term environmental and public health implications of the releases. Pertinent information and data are made available to various official state and other agencies, and provisions are made to effect protective measures if these should be deemed necessary or desirable.

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