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Review of Emergency Radiological Instrumentation and Analytical Methods at NMSS-Licensee Sites

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ABSTRACT

This report provides a brief review of emergency radiological monitoring instrumentation capabilities based on visits to Nuclear Materials Safety and Safeguards (NMSS) licensees and on a review of the open literature. Recommendations based on findings are made with regard to instrument design and operation, training, calibration, testing, analytical methods, sampling procedures, and quality assurance. An assessment of currently available instrumentation is made with respect to types of instruments, instrument specifications, future needs of NRC/NMSS licensees as seen by instrument manufacturers and extent to which those needs will be met.

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SUMMARY

Pacific Northwest Laboratory has conducted a review of emergency radiological monitoring instrumentation capabilities at Nuclear Materials Safety and Safeguards (NMSS) licensee sites and has made an assessment of currently available instrumentation.

The review of the emergency radiological monitoring instrumentation capabilities was based on visits to NMSS licensees and on a review of the open literature. Recommendations based on these site visits and open-literature review are made with respect to instrument design and operation, training, calibration, testing, analytical methods, sampling procedures, and quality assurance. The information obtained on commercial instrumentation currently available to NMSS licensees and other users was obtained through a questionnaire sent to manufacturers and vendors and by a review of commercial instrument catalogs. The assessment of currently available instrumentation is made with respect to types of instruments, instrument specifications, the future needs of NRC/NMSS licensees as seen by instrument manufacturers and the degree to which those needs will be met.

Instrumentation currently available and in use at NMSS licensees appears to provide adequate monitoring of potential radiological accident conditions. Generally, problems identified in the site visits were minor and pertained to the use and maintenance of emergency instrumentation, not inadequacies of the instruments themselves. The responses of manufacturers and vendors regarding future instrumentation needs of NRC/NMSS licensees and the methods by which they will be met show that: 1) there are some manufacturers that are sensitive to or at least knowledgeable of NRC/NMSS requirements and future needs, and 2) that some manufacturers plan to improve or modify existing systems or to introduce completely new systems to meet those needs. Most of the improvements involve the incorporation of computerized systems for data analysis and control or new types of detectors.

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REVIEW OF EMERGENCY RADIOLOGICAL INSTRUMENTATION
AND ANALYTICAL METHODS AT NMSS-LICENSEE SITES

1.0 INTRODUCTION

The ability of NMSS license holders to carry out emergency radiological actions depends largely on the instrumentation available to measure and assess the severity of an accident. To determine the adequacy of available emergency instrumentation and analytical methods at NMSS licensee sites, the Nuclear Regulatory Commission (NRC) requested Pacific Northwest Laboratory (PNL)* to evaluate existing emergency radiological instrumentation and analytical procedures at selected licensee sites and to provide recommendations which, if observed, would ensure that emergency capabilities are not compromised by inadequate equipment.

The numbers and kinds of emergency instruments needed to ensure an adequate response level are a function of the radioactive materials inventory and types of operations performed at any given facility. The radiotoxicity and chemical form of the material, as well as the quantity and operations performed, varies widely among NMSS licensees. Thus, not all facilities have the same accident potential or projected radiological consequences, and differing levels and types of emergency instrumentation may be required to achieve a suitable capability.

The first phase of the study is directed towards categorizing NMSS licensees according to projected hazards from maximum credible accidents (MCA) to provide a basis for generically determining the instrumentation capability required for adequate management of the emergency situation. An examination is also made of the capabilities of available state-of-the-art instrumentation and analytical methods applicable to emergency conditions resulting from the MCAs.

The second phase of the study addresses the adequacy of available instrumentation and analytical techniques, correlating this with various categories of licensed facilities previously developed. Deficiencies are identified and changes in procedures and instruments are suggested to correct the deficiencies.

The final phase of the study assesses current commercially available instrumentation with respect to types of instruments, instrument specifications, and the future needs of NRC/NMSS licensees as seen by instrument manufacturers and to what extent those needs will be met.

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* Operated by Battelle Memorial Institute for the U.S. Department of Energy.

2.0 CLASSIFICATION OF NMSS LICENSEES

Projected conditions resulting from an accident are highly variable because of the wide diversity in operations, the type and quantity of radioactive materials, and site specific factors of NMSS licensees. This is often a source of confusion to both licensees and regulators in selecting instruments and analytical procedures for emergency response. Since instrumentation needs will vary greatly from licensee to licensee, a classification system based on accident potential was developed for application to NMSS licensees to provide a common basis for determining emergency instrument needs.

Several characteristics are considered in the basis of classification, including:

- quantity of activity
- type and energy of radiations
- physical or chemical form of the radioactive materials
- specific types of operations involving radioactivity
- hazards potentially posed by the radionuclides.

Although the first four characteristics are essential to any scheme used as the basis for selection of radiological instruments, no single one is adequate in and of itself. For example, a system based solely upon quantity of activity does not consider the ability of the instruments to detect the particular type and energy of radiation; thus, if tritium were the nuclide in question, a typical Geiger-Mueller (GM) portable survey meter using a thin metal wall tube would be useless, although such an instrument might be useful for assessing the contamination hazards from beta emissions with higher energies such as ^{32}P or ^{90}Sr-^{90}Y. Similarly, again assuming a tritium hazard, the chemical, e.g., oxide versus molecular) and physical (e.g., gas versus liquid) forms also need to be considered because these also affect instrument requirements. The type of operations (e.g., glove-box enclosure versus open hood) may determine other necessary instrument characteristics.

The classification system developed considers the first four characteristics in addition to the potential hazards of the specific radionuclides for which the license is issued. Thus, the emergency preparedness concept is evaluated holistically but with emphasis on the protection of the general public.

Once the basis for classification was defined, broad categories of NMSS licensees were developed according to the measurement needs posed by projected MCA conditions. These are summarized in Table 2.1, which lists, for each of the categories developed, a key word description along with specific levels of dose rate and activity concentration that may be encountered during postulated MCAs. This study was not concerned with accident scenarios, risks of accidents, or site specific MCAs, but rather with the measurement and assessment of conditions created by the MCAs. The radiation and radioactivity concentration levels shown in Table 2.1 were derived from the largest possession limits in current NMSS licenses and should vary in direct proportion with changing possession

TABLE 2.1. Categories of NMSS Licensees

Category	Description	Parameters	Emergency Levels/ Measurement Consideration
I	Criticality	Fissile materials in amounts sufficient to support a chain reaction	A) External photon dose rates up to several hundred rad/h B) Airborne mixed fission products up to 5 Ci/m^3 C) Surface contamination (alpha) to 10^6 dpm/100 cm^2
II	High-hazard high-Activity airborne release	Kilocurie plus amounts of halogens and noble gases (fluid form and particulate) (^{126}I, ^{131}I, ^{133}Xe, α, β^-, γ emitters)	A) External dose rates up to 100 rad/hr B) Airborne concentrations of various radionuclides, including radioiodines, to 10 Ci/m^3
III	Low-hazard high-activity release	Kilocurie amounts of relatively low-energy beta emitters (^3H, ^{14}C, ^{32}P)	A) External dose rate dependent on energy of radionuclide but not significant B) Airborne concentrations, probably gaseous rather than particulate, to 50 Ci/m^3
IV	External radiation hazard	High-activity sealed sources (^{60}Co, ^{137}Cs)	A) External photon dose rates to 10^4 rad/h B) No airborne contribution unless source breached

limits, assuming no change in operations or engineered controls. The levels given are upper limits and should be considered as such. With the exception of Category I, Criticality, the limits cited in the table may be one to several orders of magnitude greater than those that would actually be incurred because of a smaller inventory of licensed material.

Nearly all acute hazards will result from airborne radioactivity releases or direct penetration photon radiations. Surface contamination as from airborne fallout and liquid releases to stationary or moving bodies of water are unlikely to pose actual emergency monitoring problems except possibly in the case of an accidental criticality, which might scatter alpha-emitting fissile material of high radiotoxicity (e.g., ^{239}Pu) outside the area in which external dose rates are of concern.

No single simple classification scheme can achieve unambiguous categorization; a few facilities will, of necessity, fall into more than one category as they are large and diversified with potential for several types of accidents. In this case, the instrumentation should be adequate for conditions in each category in which the facility fits.

Category I facilities are those possessing fissile materials (^{239}Pu, ^{233}U, ^{235}U) in quantities sufficient to support a self-sustaining chain reaction. A criticality accident may pose immediate life threatening or significant internal and external radiation hazards at both onsite and offsite locations. The yield of a criticality accident would be on the order of $10^{17\pm2}$ fissions, potentially capable of producing estimated airborne fission product concentrations of up to about 5 Ci/m^3 beyond the focus of points at which a lethal dose would be incurred. Fission products confined to the immediate area of the event could produce exposure rates of several hundred R/h or greater for a short time after termination of the fission chain reaction. Beta exposures in excess of 10^4 rad/h might also be observed near the point of criticality. Hence, for lifesaving purposes, instrumentation with high-range capability will be required. However, a few hours post-accident, exposure rates should not exceed 50 or 100 R/h.

Offsite concentrations of airborne activity could approach several curies per cubic meter, largely of short-lived chemically inert noble gases. Since these are beta emitters, they primarily produce an external hazard from immersion in the cloud. However, significant quantities of radioiodines and radiostrontiums may also be released to the environment, necessitating some measurement capability in this regard. In addition, alpha-emitting material may be volatilized or released in particulate form and plate out on surfaces outside the zone of external hazard. Thus, capability for monitoring alpha surface contamination and perhaps alpha air activity may be required.

An important capability for emergency assessment of a criticality accident is to identify and quantify specific nuclides. This is ordinarily accomplished by sampling and laboratory evaluation, usually by gamma spectroscopy. However, because accident dosimeters (foil activation devices) may need to be processed on an emergency basis, radioactivity counting equipment and pre-established procedures are required.

Category II includes reprocessing facilities and source production/manufacturing sites with potential for large releases of both gaseous and particulate radioactivity. The latter could include transuranic elements, as well as fission products, and the former radioiodines and noble gases. Radionuclide concentrations near the point of release may be as great as 10 Ci/m^3, with exposure rates to 100 R/h.

Category III facilities are those with the potential to release relatively large activities of low-energy beta emitters such as ^{14}C and ^{3}H to the atmosphere. Even a large release of radioactive material from facilities in this category would probably not pose actual health hazards but could result in exposures in excess of the maximum permitted for the general public. Air concentrations to 50 Ci/m^3 near the point of release are possible for low-energy, pure beta emitters such as ^{3}H, with the specific concentration largely dependent upon the quantity and form of the material and nature of the accident.

Category IV is composed primarily of facilities possessing high-activity sealed sources, including radiographers. Emergency consideration is not ordinarily required unless a source is ruptured or otherwise loses integrity; in this case, Category II applies. However, if a kilocurie activity source is lost or damaged or sticks in an open position, adverse health effects could be incurred as a result of exposure to high-level radiation fields. Photon radiation fields of 10^4 R/h or greater could require measurement.

3.0 INSTRUMENT SELECTION, SUITABILITY, AND TERMINOLOGY

Knowledge of the nature and extent of the spectrum of potential emergencies is a necessary prerequisite to selection of appropriate emergency instrumentation. Intelligent determination of the suitability of an instrument for emergency use also demands a certain degree of general knowledge regarding radiological measurements, as well as knowledge of the specific characteristics of the instrument. Therefore, this section was developed to provide a cohesive discussion of the technical bases on which emergency instrument selection should be made.

3.1 BASIS FOR SELECTION

In selecting emergency instrumentation, the licensee should be able to answer the following questions:

- Does the instrument measure the appropriate radiation(s)?
- Does the instrument have a range of measurement consistent with the accident potential of the facility?
- Is the instrumentation system suitable for the conditions under which it may be used (e.g. outdoors in harsh winter environments; in high humidities, etc.)?
- Do suitable numbers of instruments exist?
- Are suitable emergency analytical criteria and procedures available in addition to the instrumentation?
- Has the instrument been calibrated (and, ideally, evaluated) for emergency levels and conditions?
- Are personnel adequately trained and knowledgeable in emergency instrument use?

Clearly, affirmative answers to these questions are required. The licensee, perhaps assisted by the licensing agency and other outside experts, should attempt to answer the questions in the approximate order given, seeking an affirmative answer to each. The order is important in that the first three questions basically deal with the physical capabilities of the instruments, which, if suitable, may bear on the number required. The final three questions relate to operational aspects that are accomplished after the instruments have been acquired. For example, calibration needs and facilities may often be directly determined by the specific instrument(s) used; obviously, procedures and training are determined to a great extent by the specific instruments available.

3.2 PRIOR WORK

Regrettably, although the literature relating to radiological emergencies and emergency planning is extensive, relatively little is pertinent to emergency instrumentation capabilities or is highly site specific. Thus, there exists no convenient comprehensive and up-to-date guidance for the NMSS licensee or licensor. Laboratory counting and instrumentation and emergency analytical procedures are commonly ignored indicating that the need for research in this area is acute.

There is, however, some guidance available in the older literature that is applicable to the present day. Keene et al. (1963) prepared an excellent overview of emergency planning for radiation accidents and included consideration of emergency instrumentation requirements. Among the salient points made were these:

- Instruments for use in rescue operations should have capability to 5000 R/h or integration to 600 R.
- High-range emergency instruments may be provided through special purchase or by special detectors, shields, or other accessories that increase the range of routinely used monitoring instruments.
- Emergency instruments should maintain capability over extended periods of nonuse.

Other general guidance was provided by McBride and Cunningham (1972).

Two other older works bear mention. The first is a paper by Fish (1965) originally presented in 1963, that deals exclusively with dosimetry and instruments for radiological accidents. This work is succinct and, although dated, identifies many important aspects of emergency radiological instrumentation selection, use, and maintenance that might otherwise go unrecognized. Written as guidance "...to assist those responsible persons whose primary occupation is not that of a health physicist," it succeeds. It also might serve as the model for an updated regulatory guide or similar advisory.

The other is a paper by Kiefer and Maushart (1965) presented at a World Health Organization symposium that considered emergency radiological equipment needs. They noted five special requirements for emergency instrumentation: 1) measure higher doses than normal, 2) obtain results more quickly than usual, 3) make a larger number of measurements than usual, 4) carry out measurements in usual areas, in the open air, in cars, in trucks, or in provisional laboratories, 5) use unskilled personnel for making measurements and taking samples. To these should be added the consideration of the potential use of the instruments, e.g., to evaluate the potential dose to those involved in rescue operations or in evacuating a populated area. These factors indicate a need for reliability and accuracy that might not otherwise be required.

Perhaps the most germane and extensive work is a study of emergency instrumentation preparedness performed by PNL under contract to the Atomic Energy

Commission and, later, its successor agency, the Energy Research and Development Administration, during the early and middle 1970s. In the first phase of the work, performed in 1970, emergency instrumentation capabilities were examined at 33 sites, including 19 reactors and 11 Atomic Energy Commission facilities (Selby and Unruh 1971). This work revealed that:

- Instrumentation used for routine radiological measurement should also be capable of providing suitable information in an emergency, but lacks adequate range.

- Selection and placement of instrumentation used for monitoring normal controlled releases does not assure applicability to the emergency situation.

- Instrumentation and needs at power reactors were not generally comparable to those at other facilities.

- Capabilities of continuous monitoring instrumentation generally decreased with the accident potential of the facility.

Other phases of the study provided guidance on emergency instrumentation for reactors (Selby et al. 1973), mixed-oxide fuel-fabrication facilities (Andersen et al. 1972), fuel-reprocessing plants (Andersen et al. 1974), and emergency instrumentation performance, evaluation, and calibration criteria (Bramson et al. 1974). On the one hand, the latter study is particularly useful in that it provides a comprehensive examination of emergency radiological instrument capabilities for field monitoring and sampling, but on the other hand, the capabilities and tests put forth may be beyond what is necessary at many NMSS-licensed facilities, except perhaps for the larger fuel cycle activities. Moreover, it is doubtful that commercial instrumentation now available has been suitably evaluated for conformance with, or is even designed to meet, the performance criteria put forth by Bramson et al.(1976). Also, the work is essentially mute on counting laboratory instruments and emergency analytical procedures.

In addition to the PNL study, there are a few standards published by the American National Standards Institute (ANSI) that have application, albeit limited, to emergency instrumentation at NMSS sites. These include ANSI N13.5-1972, which provides performance specifications for pocket dosimeters and ANSI N323-1978, which does the same for radiation protection instruments (ANSI 1972; ANSI 1978b). In addition, ANSI N320-1979, specifically deals with emergency radiological monitoring instrumentation (ANSI 1979). Although this latter ANSI standard is specific to reactors, it generally applies to NMSS facilities (particularly the larger ones) as well. The ANSI standards are at best only of peripheral applicability, as is also true of the Institute of Electrical and Electronic Engineers (IEEE) standards. Regulatory Guide 8.25 discusses the frequency of calibration, error limits for measurement of air sample volume, and documentation of calibration for routine and emergency air sampling programs (U.S. NRC 1980a).

Largely as a result of the accident at the Three Mile Island Nuclear Station, attention has been focused on reactor emergency instrumentation. Specific guidance for power reactors is provided by Regulatory Guide 1.97 (U.S.

NRC 1981) and the compilation of Lahti et al. (1980) for various types of emergency monitoring instrumentation. Although specific to power reactors, some of the guidance is applicable to NMSS licensees. More general guidance is provided by Schmidt (1978), who reported on the recommendations of the Federal Interagency Task Force on Offsite Emergency Instrumentation. This work, while limited to monitoring in the environs following a major accident (as from a power reactor), is nonetheless largely applicable to potential accident situations at least at the larger NMSS-licensed facilities. NUREG-0654/FEMA-REP-1, Revision 1 also discusses some of the emergency instrumentation needs for post-accident situations at nuclear power plants which may be applicable here (U.S. NRC 1980b).

The reliance of licensees on commercially available instrumentation raises questions with regard to the adequacy of the instrumentation, both from the standpoint of performance and of meeting the needs of the licensee in the emergency situation. Evaluation of stated or claimed performance is still in its infancy, and the user must often rely on what information is provided by the manufacturer regarding performance. Then, too, the user may not be able to clearly state or even understand needs or, if stated, to obtain the appropriate instrumentation. Indeed, the site visits revealed that, in general, little or no consideration is given to ruggedized instruments. For example, although portable survey instruments may be called upon to perform outdoors in a variety of environmental conditions, there is frequently no provision made for waterproofing, low-temperature operation, operational checks (other than battery test), a self-contained scale or meter illumination, or various human factors.

3.3 TERMINOLOGY

To provide unambiguous use of instrument terminology in the remainder of the report, this section gives a brief description of general instrument types and their more common use. These include sample analysis instrumentation, survey meters, remote-area monitors, and continuous-air monitors.

Instruments used for sample analysis (i.e., those used in the counting room to determine sample activity) include typical laboratory counting equipment and spectroscopy systems of varying degrees of sophistication. The sample is usually a wipe of removable surface contamination or an air particulate filter, although liquid samples or others requiring radiochemical treatment prior to counting might also be included.

Survey meters are small, hand-held, rate meters for mixed beta-photon, photons only, beta-alpha, or neutron radiations. Some may have dose or exposure integrating capability. Included with the survey meters are surface contamination monitors, which are simple count-rate instruments that provide a quick method of scanning equipment or personnel for radioactive material, and personal alarm dosimeters or detectors. These instruments are equipped with self-contained (i.e., battery) power supplies.

Remote-area monitors continually measure ambient radiation levels and provide an audible or visual signal when external radiation levels have exceeded a preset point. These are usually ac powered and are permanently located. Continuous-air monitors provide a continuous readout of airborne radioactivity concentrations and may also have solar capability. Air-sampling devices are simply air-moving or channeling devices that draw air through a filter or other collecting medium for subsequent analysis.

4.0 CURRENT STATUS OF EMERGENCY INSTRUMENTATION AT LICENSEE SITES

Several site visits were made to NMSS-licensed facilities to gather first-hand information and to augment the limited amount of published material concerning analytical methods and instrumentation applicable to accident conditions. Selection of specific sites to visit was based on the desire to obtain a representative cross section of licensees, the funding and time constraints, and the willingness and cooperation of the licensee. Facilities with large radioactive material inventories were selected for two reasons. The first was to visit larger sites to maximize the amount of information gained. The second reason is that, of the several thousand NRC materials licensees, only a few with the greatest licensed activity (i.e., those amount which could cause significant offsite doses), were required to maintain a formal emergency contingency plan, including emergency radiological instrumentation. Visits were made to two fabrication facilities, one large research institute, an isotope production facility, and a radioisotope storage/distribution center.

The licensees were asked open-ended questions that reflected primary interest in the following areas:

- radiological instruments presently used for sampling and sample analysis, field surveys (i.e., portable survey meters) and monitoring, including alarming instruments
- use of instruments or instrument readings to assess the nature and severity of an accident
- maintenance and calibration and
- other factors affecting instrument accuracy and the efficiency of analytical response.

These subjects are considered in the following discussion.

The general types, applications, and measurement ranges of observed instrumentation are listed in Table 4.1. Examples of specific instruments observed during the site visits and available commercially are given in Appendix A. An impressive variety of commercial instrument models and types was noted during the site visits. Instrument inventories were continuously upgraded and changed as new models become available; however, this may not be true for smaller licensees.

In general, when licensees bought commercial instrumentation, they did not take into account the instrument's specifications with regard to emergency use. Anticipated routine monitoring conditions were used for purchase specifications. Therefore, some of the currently used instruments were inadequate for the specific type of emergency situations that might be encountered. The choice of inadequate instruments may have also occurred due to the licensee handicap of receiving incomplete or inadequate specifications from the manufacturers and vendors of instrumentation. At present, there is a paucity of suitable instrumentation standards and guides for general application in the field.

TABLE 4.1. General Instrument Types, Applications, and Measurement Ranges

Instrument Type	Applications	Measurement Ranges
A. Sample Analysis (Analysis of wipe and air filter samples)	1) Gamma spectroscopy systems 2) Gas flow counters for α, β^-, γ 3) Liquid scintillation counters for low energy β^-	Few nCi to several mCi level sample dependent upon background and geometry.
B. Portable survey meters (Determination of β, γ, neutron dose rate and α, β^-, γ surface con- contamination)	1) Small volume (<50 cm^3) ion chambers, mostly nonpressurized for high-rate fields 2) Medium-volume ion chambers for mixed β^-/γ radiations 3) Thin window GMs for contamination surveys 4) Gamma insensitive neutron rate meters.	<u>Dose Rate</u> 0 - 10 R/hr (β^-, γ) 0 - 20 R/hr (neutron) <u>Contamination Level</u> 0 - 1.5 x 10^5 cpm (α, β^-, γ)
C. Fixed monitoring/alarming (Determination of criticality events and abnormal radiation levels in an area)	1) Multiple ion chamber systems for criticality monitoring (2 of N system, where minimum of 2 detector trips required for alarm) 2) Single ion chamber, GM, or scintillating detector for other external γ field alarming situations 3) Constant-flow air samplers for α, β^-, γ airborne contaminants 4) Passive criticality monitors for post-accident evaluation (require laboratory evaluation).	0 - 100 R/hr with adjustable alarm (local and remote, visual and audible alarms)

4.1 TRAINING

Although all licensees visited gave a positive response to having personnel adequately trained in the use of radiological instruments, only three of eight have established retraining programs. The remaining five gave informal instructions on an infrequent and ad hoc basis. The quality of the training programs was not assessed. Two facilities ran annual drills simulating serious accidents to test existing emergency preparedness plans. Therefore, the researchers concluded that licensees generally assigned a low priority to personnel education and relied heavily upon incoming expertise or on-the-job training.

4.2 MAINTENANCE AND TESTING

All facilities reported a maintenance and testing program to some extent for radiation-detection and measurement equipment. Half of the licensees required a periodic operations check of emergency instrumentation at time intervals ranging from daily to semimonthly, while the remainder performed such checks infrequently or not at all. An operational check consists of obtaining a single-point, instrument reference reading with an uncalibrated (i.e., nonreference or traceable) check source to ensure that the instrument is in fact responsive to radiation and is set at approximately the correct level. The physical condition of the instrument should also be inspected and the power supply (if dc) tested.

The operational check supplements the periodic calibration and provides an extra degree of confidence that emergency monitoring equipment will be operational when needed. Operational checks at intervals greater than quarterly are considered inadequate. Therefore, half the facilities visited were observed to be deficient in this area.

4.3 CALIBRATION

Determination of response or readings of an instrument to a series of known radiation values over the range of the instrument (i.e., the calibration) is well established for routine analytical counting equipment. Most facilities calibrated against a National Bureau of Standards (NBS) traceable source with an activity generally less than 1 μCi. This may be satisfactory for monitoring routine operations of near background activity but is inadequate for analysis of high-activity samples expected during an accident. In many cases, the activity in accident samples were expected to exceed the measurement capability of instruments used for routine analysis.

Most facilities planned to identify high-activity samples by using a scanning procedure that permits them to be isolated for special handling and analysis. Unfortunately, samples so identified were not assured of analysis with designated equipment or were to be analyzed after a significant alteration (e.g. changes in source to detector distance or change in shield configuration) in the physical setup of the system. This requires additional time and, most importantly, reflects abnormal or nonstandard operating procedures for which the licensee was generally unprepared.

Calibration of portable survey meters and fixed alarming monitors to accident level conditions created a special problem for the licensees because of the high dose rates involved. Most facilities chose to send high-rate instruments to a vendor for calibration, because of the convenience and to avoid the costs of high-level radiation facilities used only on an occasional basis. In addition, limiting radiation exposures to personnel was a consideration. A few facilities visited were capable of calibrating high-level or emergency monitoring instruments, at least from a physical facilities standpoint, while others expressed no concern for high-level calibrations.

Those facilities dependent upon a vendor to calibrate instruments were frequently aware of only one parameter involved in the calibration. Except for calibration energy, little was known about the vendor's physical setup, how many points (or even if any) on each scale were checked, or whether the power supply or linear response was tested before calibration. Similarly, the response to radiation levels beyond the range of the instrument or the effects of such basic environmental variables as temperature and humidity were generally not known. Information on the parameters listed above is valuable to the licensee in determining if the calibration satisfies their needs.

The problem was much the same with regard to air sampling and monitoring instrumentation. Air flow of the pumping device and the efficiency of the collecting medium are two critical parameters in air sampling (U.S. NRC 1980a). A rotameter was commonly used to calibrate vacuum pumps; other methods mentioned included in-line testing and multiple intercomparisons. Calibration was not normally accomplished under filter loading conditions, nor was an appraisal made of air in-leakage. Only three of the licensees visited actually determined filter efficiency. These used the "two filter method" in which filter efficiency was obtained from the ratio of sample counts from two in-line filters. The remaining facilities either assumed 100% efficiency or relied upon published manufacturer's specifications.

The frequency of calibration for radiological equipment varied widely: licensees quoted periods of "daily," "monthly," "as used," and "as needed" for analytical instruments. Portable and fixed-monitoring instruments and air samplers were calibrated at semiannual or quarterly intervals as specified by license conditions. Other questions concerning calibration details triggered unanimous or nearly unanimous positive responses such as:

- Are instruments calibrated exactly as required by the licensee?
- Is the calibration energy approximately the same as that encountered in the field?
- Are instruments tagged with calibration dates and all pertinent information that affect readings?
- Are complete records kept for each calibration?

4.4 INTERPRETATION OF INSTRUMENT READINGS

The facilities visited relied largely upon the past experience and training of the radiological safety staff to interpret portable radiological instrument readings. This subject was not observed in licensee procedures and existing training programs only briefly mentioned this aspect of accident assessment.

Interpretation of fixed instrument readings was also observed to be deficient. Most licensees had calculated only one point of a release rate (such as from an instrument readout in cpm or mR/hr to μCi/sec for a stack monitor), and that was the alarm point. The potential is therefore great that, if a stack release occurs, the magnitude of that release could not be determined in a timely manner. Most stated that, using instrumentation readout data, a calculation could eventually be performed to determine the amount of material released to the environment. The researchers doubted, however, that this calculation could have been completed in sufficient time to be of use in an emergency.

4.5 QUALITY ASSURANCE

Vague answers were given to questions concerning the quality assurance (QA) of radiological instruments. Only half of the facilities visited reported ongoing QA programs. The others stated that they had infrequent or incomplete reviewing procedures. Several sites with established programs described rather extensive efforts to assure the quality of measurements. For example, two facilities reported that all daily operations were reviewed by computer to assure that records and instrument calibrations are current.

4.6 SAMPLING PROCEDURES

Most of the facilities visited had predetermined routes between sampling points and the location of analysis to avoid loss of samples and sample contamination. While this should be useful for both routine operations and emergency response, again, little consideration appears to have been given to the high-activity levels associated with accidents, including the increased likelihood of sample cross-contamination with increasing activity and the possibility of contaminating the counting equipment. In extreme cases, some samples may require shielding or special handling to avoid cross-contamination, increased background in counters, and personnel exposures. These precautions were generally not addressed in sampling procedures.

4.7 ANALYTICAL PROCEDURES

Licensees expected to use the same analytical procedures for accident evaluation as those currently used for routine monitoring. However, since most analytical equipment is designed and calibrated to measure low levels of radioactivity, samples taken under accident conditions may exceed the maximum measureable activity for fixed geometry conditions. Apparently, licensees had not considered the magnitudes of activity and the attendant handling and analytical problems that might be encountered in a post-accident situation.

4.8 INSTRUMENT GUIDELINES

Half of the licensees interviewed had established operational guidelines for analytical instruments. These were step-by-step ("cookbook") instructions for sample analysis. The others relied on instrument manuals to supply basic or supplemental information. Some facilities relied exclusively upon one or two technicians for all sample analysis. Thus, in the case where no guidelines existed and the technician was not present, the analyses could not be performed.

Instructions for operation of portable survey meters, remote area monitors, and air samplers were sometimes found in the licensing file at some facilities. In general this information was not easily or conveniently accessible, nor in fact very useful for answering questions on specific instruments because the information was not pertinent to the proper use of the instrument. In no case did emergency instrumentation operation guidelines specifically address all necessary aspects of emergency use. The guidelines were largely broad-bush treatments of limited value.

4.9 EMERGENCY KITS

All facilities either had an emergency kit or quick access to emergency equipment such as protective clothing, NOISH-approved respirators, flashlights, and communications equipment. The adequacy of the kits was variable but generally satisfactory.

5.0 RECOMMENDATIONS

Assessment of the current accident monitoring status at selected NMSS sites, coupled with a review of commercially available instrumentation, as described in the manufacturer's literature, revealed several areas of weakness and led to the development of the recommendations discussed in this section. It should be borne in mind that the recommendations are, of necessity, generic rather than specific to the needs of a small number of licensees. However, the transition of applicability to any individual licensee should be apparent and relatively easily accomplished. This does not mean that the recommendations are simplistic or superficial; rather, in some cases, they are quite deep and require a combined effort on the part of the licensees, regulatory bodies, and instrument manufacturers for implementation.

5.1 INSTRUMENT DESIGN AND OPERATION

Perhaps the single most important improvement in the emergency instrumentation area would be the establishment of basic criteria, in the form of a suitable standard, regulatory guide, or other advisory document, to guide licensees, manufacturers and regulators with regard to emergency instrumentation and procedures. Such guidance could readily be prepared using the comprehensive work of Fish (1965), Bramson et al. (1976), and others as a basis. Instrumentation performance should be verified as meeting the established criteria through actual testing and evaluation. A mechanism such as an independent testing and evaluation laboratory leading to certification of performance might also prove desirable.

In addition to development of basic criteria and instrument performance evaluations, which may be a relatively long-term generic solution to many problems, certain design and other changes can be implemented on a specific *ad hoc* basis by individual manufacturers, including:

- improved resolution of portable single and multichannel analyzers
- improved sensitivity and human factors engineering of portable monitors for gaseous low-energy beta emitters (e.g., $^{14}CO_2$, ^{3}H)
- internal audit circuitry and battery test capability on portable dc-powered units
- ruggedizing (e.g., shock mounting, weatherproofing) of instruments to permit survival of operability under extreme post-accident conditions -- this applies to both field and laboratory instruments, for the latter may be required to operate continuously and in uncontrolled atmospheres
- more detailed specifications, instructions, and troubleshooting information in instrument manuals, along with actual measurement and verification of capability rather than reliance on theory or extrapolation from less demanding conditions.

5.2 TRAINING

Ongoing training -- both formal and informal -- is needed for all employees, and especially for those participating in a facility's response team. This is particularly true for those select few charged with the responsibility for sample analysis and field measurements in the event of an emergency. For each work shift, an adequate number of trained personnel should be available to cover all onsite and offsite locations of interest. In addition, at least one and preferably two persons trained in the operation of analytical instruments should be available on short notice.

A successful training program is one that provides and maintains the individual's familiarity with high-range instrument operation and specific emergency assignments. Training intervals not exceeding one year are usually sufficient, especially if an emergency drill is included. Designated personnel should be instructed particularly in any changes in geometry, instrument settings, and technique that may be required for accident level conditions, and should also have the opportunity to make practice use of the instruments they may be called upon to use. Training is also valuable as a tool to identify problems and allow for correction prior to an emergency.

Interpretation of instrument readings has a direct influence upon measurement accuracy and should be thoroughly addressed in the training program. Training for personnel who may be called upon to use emergency radiological measurements should cover all significant points that could directly affect end results of monitoring efforts. For portable rate meters, this includes instrument orientation, self-shielding effects, angular dependence, energy dependence, tracking error, switching effects, response time and environmental effects.

5.3 MAINTENANCE AND TESTING

New radiological monitoring equipment should be tested to the extent possible when delivered to verify that manufacturing, regulatory, and licensee specifications are met. Descriptions of suggested test and calibration methods for instrumentation may be found in the reference listing at the end of this report. Several of the more important tests (e.g. linearity response) should also be performed on a continuing basis to assure proper operation. Emergency-designated equipment should be checked for response before each use and on a monthly or quarterly basis.

The following technique or one similar to it may be used for testing instrument response. Shortly after calibration of radiological equipment, a check source may be used to obtain a reference reading. This source can then be used to check the instrument response on a periodic basis. Variation of more than 25% in subsequent checks under identical conditions suggest the instrument is out of calibration or malfunctioning.

5.4 CALIBRATION

Accurate analysis of high-activity samples on an instrument calibrated for near background levels is tenuous at best. If source strength is excessive, dead time or resolution losses may be great and render the low-level calibration inapplicable. For a calibration to be valid, the test source should approximate the type and intensity of the radiation to be measured in the field. If high-level sources are used, special techniques and physical facilities may be required, and care should be exercised to assure that frequent use of the source does not violate good ALARA practices, degrade the detectors, or produce contamination problems. Calibration sources should be traceable to NBS for emergency as well as routine analyses. Appropriate or suitable NBS standards, however, are not always available and it may be necessary to obtain calibrations with nonrelatable laboratory standards.

The frequency of calibration for emergency operations will vary according to the type and use (including storage or standby operation) of the instruments. A change of source-detector geometry may be required in laboratory instruments for the high-level analyses associated with an emergency. The effects of the altered source to detector distance, dead-time losses, and backscatter need to be considered along with other factors affecting the detector response. A careful calibration of activity as a function of count rate should be made for each designated emergency instrument. This also applies to portable monitoring instruments, except that for these instruments, calibration intervals may be less frequent.

Since the interpretation of field readings may depend on firsthand knowledge of the calibration setup, this information must be available. All facilities having designated emergency response instruments calibrated by a vendor should document in detail the calibration procedures used, including any pre-calibration checks performed, a description of the physical setup (source and instrument orientation), specifics on radiation type and energy used, and the points calibrated on each scale. For exposure and dose rate instrumentation, the calibration procedure should include exposure beyond the upper range to ensure that saturation or paralysis does not render the instrument unsuitable for emergency work.

5.5 QUALITY ASSURANCE

Quality assurance requirements for emergency instrumentation and procedures are similar and no less stringent than those imposed on normal operations. Procedures need to be written, reviewed and approved in accordance with established QA requirements. Accurate and complete records of all maintenance activities, including calibrations, are vital and could be of retrospective value, including legal protection. These records should allow traceability of the activities to accepted facility standards. Finally, a periodic review must exist to assure that routine maintenance activities, calibrations, and written procedures are current.

5.6 SAMPLING PROCEDURES

Samples taken for analysis should be representative of what actually exists in the field situation. Serious problems may arise from either inaction or overreaction in emergency response caused by nonrepresentative samples. To the greatest extent possible, sampling procedures should be standardized for a particular facility and printed in a "cookbook" format.

High-activity samples are a potential source of personnel exposure and should be treated as any other unsealed millicurie source. If background permits, samples may be scanned with a contamination monitor to isolate those showing high levels. Small, shielded containers may be used, but care must be taken to avoid cross-contamination.

5.7 ANALYTICAL METHODS

Procedures for analytical methods should be established before any situation arises that requires their use. A predetermined route of analysis should be designed, including all steps between sampling and final calculation. These should be prepared in the form of written procedures that are easily understood by those who may use them. Procedures should be readily available and maintained current. Procedures should call out the location of instruments, reagents, and other items that are referenced or specified.

An increase in the background radiation may be caused by a large release of activity and may compromise low- or intermediate-level measurements. This possibility cannot be eliminated, but certain preventative steps can be taken to reduce the extent of contamination. It is not always reasonable or convenient to locate analytical equipment distant from radionuclide operations. However, the relative locations of the two should not be such that a direct pathway exists between the areas of radionuclide usage and analytical equipment. Certain positive actions such as sealing windows and doors and halting HVAC operations in the analytical areas during a release should be considered by the licensee. Of course, analytical equipment located in a building where large quantities of materials are stored should always be placed upstream (airflow) of the materials.

6.0 ASSESSMENT OF CURRENTLY AVAILABLE INSTRUMENTATION

Most studies on the application of radiological instrumentation concentrate on either routine usage or monitoring of power reactor accidents. Little information is available concerning instrumentation adequacies for accident situations at NMSS-licensed sites. The first part of this report discussed the instrumentation and procedures that a representative sampling of NMSS licensees would use during response to accidents. This section discusses state-of-the-art instrumentation that is currently available or that could be developed by the manufacturers to meet the needs of high-level or post-accident sampling. Instrumentation specifications claimed by manufacturers and vendors are stated and future instrumentation needs of NRC/NMSS licensees as seen by some manufacturers and vendors are discussed.

6.1 TYPES OF INSTRUMENTS

Instrument requirements of NMSS-licensed sites vary tremendously. However, the level of NMSS emergency monitoring is expected to fall in the range from routine radiological monitoring at materials' sites, to accident-level monitoring at nuclear power generating stations.

Many types of radiological instruments are used in industry today; however, only a few general types are of interest to this study. The following categories of instruments were considered important in assessing accidents at NMSS-licensed facilities:

- medium to high-range portable exposure and dose rate meters
- low to medium-range portable exposure and dose rate meters and contamination survey meters
- facility area, process, and criticality monitors
- continuous air monitors
- air samplers
- analytical equipment
- portable neutron monitors
- portal monitors and hand and shoe monitors
- environmental radiation monitors.

Other types of instruments and devices may be used to aid in accident assessment (e.g., meteorological equipment, dosimetry), but these fall outside the scope of this study. The instrument types listed above were considered basic to most NMSS emergency response needs.

No distinction between onsite and offsite instrumentation was made in this report. Onsite instrumentation may require ranges that are orders of magnitude greater than offsite devices. All other instrument capabilities should be similar, including the ability to operate in outdoor environments. This ability is necessary for onsite instruments because of the high potential for losing building-controlled environment capability (e.g. fire or loss of offsite power) during an accident.

6.1.1 Medium to High-Range Portable Exposure and Dose Rate Meters

NMSS licensees use portable instruments such as those described in Table 6.1 to determine medium to high-level beta-photon dose rates (i.e., 0.1 to 1000 rad/h). The detector normally used for this task is an ion chamber. Several instrument manufacturers and vendors distribute GM type detectors claimed to accurately measure exposure and/or dose rates. Some of these units are designed to measure very high exposure rates. Most GM detectors have a very large energy dependence over the energy range of 40 keV to 2 MeV and, in addition, are usually not very accurate or reliable in higher radiation fields. However, if the exposure conditions in which the instruments are to be used is known (e.g., exposure rates, nuclides, and radiation to be present), the instruments can be designed and calibrated to provide accurate readings. In general, ion chambers are more reliable and accurate for wide-range applications.

6.1.2 Low to Medium-Range Portable Exposure and Dose Rate Meters and Contamination Survey Meters

Instruments that measure lower-level radiation fields (i.e., 0.1 to 1000 mrad/h) and surface contamination (0-80K cpm), are shown in Table 6.2. Devices using scintillators and gas-proportional detectors are also useful. Caution should be exercised when using GM detectors; several factors will affect the capability of the instruments to provide useful and accurate readings. The upper dose rate limit of many GM-type instruments is considerably below 1000 mrad/h and may be even lower than 1 mrad/h. As mentioned in the preceding section on medium to high-range instruments, GM detectors have a large photon energy dependence. Also, on the lower ranges of most GM detectors, the precision (i.e., the repeatability) of the measurements can be very poor. Instruments will also have different response times for different ranges, therefore, entry into unknown radiation fields must be performed carefully and scanning rates of contaminated surfaces modified accordingly.

6.1.3 Facility Area, Process, and Criticality Monitors

The monitors shown in Table 6.3 are used to alert personnel and, in some cases, to quantify abnormal radiological conditions. Devices included in this category are area, process, criticality, and stack monitors, which will most often be the device used to detect and quantify releases to the environment. For these instruments, the monitoring point is normally placed downstream from the last material confinement barrier. An ion chamber is the most common type of detector although some devices use GM detectors. The definite advantage of an ion chamber is that it can be used in higher radiation fields without saturation of the detector response. Most monitors are equipped with remote readouts and visual and audible alarms.

TABLE 6.1. Medium to High-Range Portable Exposure Rate Meters

Manufacturer	Model	Detector	Radiations Detected α	β	γ	Range	Accuracy	Energy Dependence	Scale
Berthold	TOL/E, LB 1310	IC*	x	x	x	0-3 KR/h 0-300 R integration		±10% from 10 KeV to Co-60	
Eberline	RO-2, RO-2A	IC		x	x	0-50 R/h		±10% from 20 KeV to Co-60	Linear
Eberline	RO-3C, RO-3D	IC		x	x	0-100 R/h		±10% from 10 KeV to 1 MeV	Linear
Eberline	RO-7	IC		x	x	0-1.9 R/h 0-100.0 R/h 0-19.99 KR/h			Digital
Eberline	PIC-6A	IC		x	x	1 mR/h to 1000 R/h			Log
Eberline	6112B	IC			x	0-1000 R/h			Log
Eberline	6112D	IC			x	0-1000 R/h			Digital
Jordan	Radector I AGB-500B-SR	IC		x	x	0.5 mR/h to 500 R/h	±20%	Independent over range 80 KeV to 1.2 MeV	Log
Jordan	Radector III AGB-100-SR	IC		x	x	0.1 mR/h to 1000 R/h	±20%	±15% 80 KeV to 1.2 MeV	Log
Jordan	Radgun AGB-10KG-SR	IC		x	x	0.05 mR/h to 10 R/h	±20%	Independent 80 Kev to 1.2 MeV	Log
Keithley	36100	IC		x	x	0-20 R/h		±10% from 12 KeV to 2 MeV	Digital
Ludlum	77	GM**			x	0-1K R/h			Log
Ludlum	17	IC			x	0-50 R/h			
Technical Associates	CP-44	IC	x	x	x	0-25 R/h	±5%		Linear
Technical Associates	CP5 Mark III	IC		x	x	0-250 R/h	±15%		Linear
Victoreen	470 A Panoramic	IC		x	x	0-1000 R/h	±10%	±15% 10 KeV to 2 MeV	Linear

* IC - Ion Chamber
** GM - Geiger Mueller Detector

TABLE 6.1. (cont)

Manufacturer	Model	Detector	Radiations Detected α	β	γ	Range	Accuracy	Energy Dependence	Scale
Victoreen	471	IC	x	x	x	0-300 R/h	±10%	±10% 6 KeV to 2 MeV	Linear
Victoreen	740 F Cutie Pie	IC	x	x	x	0-25 R/h	±10%	±15% 40 KeV to 2 MeV	Linear
Xetex	302 B	GM			x	0.01 to 1000 R/h	±15%	±15% 70 KeV to 1.3 MeV	Digital

TABLE 6.2. Low to Medium Range Portable Exposure Rate and Contamination Survey Meters

Manufacturer	Model	Detector	Radiations Detected α	β	γ	Range	Accuracy	Energy Dependence	Scale
Berthold	LB-1210	Xenon-filled proportional counter	x	x	x	0-3000 Counts/Sec			Log and Digital
Berthold	LB-1200					0 x 10^4 cpm 0-100 mR/h			Log
Berthold	LB-133	Proportional counter				0-3E4 $\frac{uSv}{h}$		20 KeV to 1.3 MeV	Log
Dosimeter Corp. of America	3795	GM	x	x	x	0-100 mR/h	±10%	±20% 10 KeV to 2 MeV	
Eberline	E-140	GM	x	x	x	0-50 mR/h 0 x 10^4 cpm	±5%		Linear
Eberline	E530N	GM			x	0-20 R/h	±5%		Linear
Eberline	RM-14	GM		x	x	0 x 10^4 cpm	±5%		Linear
Eberline	PAC-ISAGA	ZNS Scintillator	x			0-2 x 10^6 cpm			Linear
Eberline	PAC-4G-3	Gas Proportional	x			0-5 x 10^5 cpm	±10%		Log
Ludlum	2, 3	GM or scintillator	x	x	x	0-50 mR/h & 0-200 mR/h			Linear
Ludlum	5	GM	x	x	x	0-2 R/h			
Ludlum	14C	GM	x	x	x	0-2 R/h			Linear
Technical Associates	PUG-1 PUG-1AB PUG-1E	GM	x	x	x	0 x 10^5 cpm			Linear
Victoreen	490 Thyac III	GM				0 x 10^4 cpm	±10%		Linear
Victoreen	492				x	0-1 R/h	±20%		Linear
Xetex	305A	GM		x	x	0.1 to 9.99 x 10^4 mR/h	±15%	±15% 60 KeV to 1.3 MeV	Digital

TABLE 6.3. Facility Area, Process, and Criticality Monitors

Manufacturer	Model	Detector	Range	Accuracy	Supply	Scale
Eberline	EC4-X	GM and IC	0.01 mR/h to 10 KR/h	Visual and Audible	AC	Linear
Eberline	RM-14	GM	0-5 x 10^4 cpm	Visual and Audible	AC/DC	Linear
Eberline	RM-20	GM	0-5 x 10^4 cpm	Visual and Audible	AC/DC	Linear
Eberline	RM-21	GM	10^1-10^6 cpm 1-10^4 mR/h	Visual and Audible	AC/DC	Log
GA Technology	GA "6-PAC"	IC	10^1-10^4 R/h	Yes, Output	AC	
GA Technology	RS-2A	IC	10^1-10^4 R/h	Yes	AC	
GA Technology	RS-2D	IC	10^1-10^4 R/h	Yes	AC	
Jordan	RAMP-IV	IC	1 mR/h to 1000 R/h		AC	
Ludlum	177	GM or Scintillation	0-5 x 10^5 cpm	Audible, Visual, and Adjustable	AC/DC	Linear
Ludlum	300	GM	0.1-1000 mR/h	Audible, Visual, and Adjustable	AC/DC	Log
Nuclear Measurement Corporation	NM-6	Moderated B-10 phosphor for neutrons	1-10^5 mR/h	Audible and Visual	AC	Log
	NM-6M	Moderated B-10 phosphor for neutrons	1-10^5 mR/h	Audible and Visual	AC	Log
Nuclear Measurement Corporation	GA-6M	Scintillator	0.1-10^4 mR/h	Visual and Audible	AC	Log
	GA-6	Scintillator	1-10^5 mR/h	Visual and Audible	AC	Log
Nuclear Research Corporation	AR-2	GM	10-10^6 cpm	Visual	AC	Log
	DRM-100	GM		Visual and Audible	AC	Digital
	TA-90A	GM	0.1-10^4 mR/h	Visual and Audible	AC	Log
Technical Associates	WA-2A	GM	0.1-1 R/h	Audible and Visual	AC	
	FML	GM	0.01 mR/h to 10 R/h	Audible and Visual	AC	

TABLE 6.3. (cont)

Manufacturer	Model	Detector	Range	Accuracy	Supply	Scale
Victoreen	808D	GM	0.01-10 R/h	Audible and Visual	AC	
Victoreen	845	IC	0.1 to 10^7 mR/hr	Audible and Visual	AC	Log
Victoreen	855	IC	0.01 to 10^4 mR/hr	Audible and Visual	AC	Log

6.1.4 Continuous Air Monitors

Continuous air monitors (CAMs) are used to determine the concentration of radioactive air contaminants at specific facility locations. Monitors of this type are described in Table 6.4. CAM units can be used to determine: 1) gaseous radioactivity, 2) particulate radioactivity, 3) or radioiodine concentrations. In some cases they also alert personnel to abnormal radiological conditions. Some systems can measure these three different classifications of radioactivity simultaneously. Visual and audible alarms and remote readouts are available for many units.

Gaseous radioactivity monitors, continuously or at set time intervals, sample quantities of air and measure the radioactivity present in the gaseous state. Such instruments are usually flow-through ionization chambers which are continuously flushed with air. Unless appropriate precautions are taken, flow-through and similar type gaseous monitors will also measure radioactivity present in or on solid particles suspended in air, and will also respond to ambient external radiation fields. In general, gaseous radioactivity monitors are most useful for radionuclides such as the noble gases where the limiting concentration is related to external dose from beta emission, and for low energy beta emitters such as ^{3}H and ^{14}C which are internally hazardous. Gaseous radioactivity monitors should be equipped with filters to remove interferences from particulate radioactivity, and they must operate in fields ≥0.1 mrad/h, without adverse effects on measurement capability.

Particulate radioactivity monitors measure only the radioactivity present in or on particulates suspended in ambient air. They filter or remove the particulates from a measured volume of air, and continuously or periodically measure the radioactivity in the material removed. Most CAM units draw air through a moving paper filter or a fixed filter that is monitored with a radiation detection device.

Monitoring of radioiodines may be accomplished in a variety of ways, but consideration must be given to the chemical and physical state of the radioiodine. The applicability of the instrument for molecular iodine, methyl iodide, and particulate iodines needs to be considered. Some radioiodine monitors incorporate the use of activated charcoal filters and others use silver zeolite cartridges to capture the radioiodine for determination of radioactivity levels present.

6.1.5 Portable Air Samplers

Portable air samplers (described in Table 6.5) can be used to obtain samples of air contaminants at locations where continuous air monitors are not available or when accurate measurements are required. The sampling determines radioactive iodine, gas, and particulate concentrations in onsite and offsite locations. Samples are normally analyzed at a centralized or remote counting facility that is equipped with high-resolution analytical instrumentation.

TABLE 6.4. Continuous Air Monitors

Manufacturer	Model	Detector	Radiations/ Radionuclides Detected	Range	Alarm	Recorder	Filter Collection
Berthold	LB 106B	Proportional	^{3}H	MDL of 1.75 x 10^{-8} Ci/m^3 @ 1 minute	No	Printer	No
Eberline	AXM-1	GM	Particulates, Iodines, Noble gases	10^2 µCi/cc I 10^5 µCi/cc Xe			Particulate and Iodine
Eberline	IM-1	Scintillation	Iodines		Visual, Audible	Chart	TEDA Charcoal
Eberline	PING-1A	Scintillation	Particulates, Iodines, Noble Gases	10-10^6 cpm	Visual, Audible	Chart	TEDA Charcoal and Millipore
Eberline	PING-3	Scintillation	Particulates, Iodines, Noble Gases			Printer	TEDA Charcoal and Millipore
Eberline	SPING-4	β^- scintillator, α solid state, GM	Particulates, Iodines, Noble gases		Visual, Audible	Remote recorder and readout	Particulate and Iodine
Eberline	AMS-3	GM	β α	10-10^5 cpm	Audible, Visual	Chart	Yes
Eberline	ALPHA-5A	Solid state	β α	1-10^3 cpm	Audible, Visual	Chart	Yes
GA Tech.	RS-58D	Scintillation	Particulates and Iodines		Yes	No	Yes
GA Tech.	RS-52D	Scintillation	β^- >150 KeV	6 x 10^{-8} to 6 x 10^{-2} µCi/cc	Visual, Audible		Particulate and Iodine
GA Tech.	RS-60D	Scintillation	Particulates, Iodines, and Noble Gases		Yes	No	Yes
Johnston Labs	955B	IC	γ --- ^{3}H --- ^{14}C ---	0.05-50 mR/h 0-10^3 µCi/m^3 0-2 x 10^3 µCi/m^3	Audible	No	No
Johnston Labs	111	IC	H^3	0-10^6 µCi/m^3	Visual, Audible	No	No
Johnston Labs	133C	IC	^{133}Xe	0.0-100 mpc	Visual, Audible	Chart	Particulate

TABLE 6.4. (cont)

Manufacturer	Model	Detector	Radiations/ Radionuclides Detected	Range	Alarm	Recorder	Filter Collection
Nuclear Measurement Corporation	AM-22 BF AM-33 BF AM-22 1F AM-33 1F	β^- Scintillator and NaI crystal	α, β^-, γ	$50\text{-}5 \times 10^4$ cpm	Visual, Audible	3 Channel Chart Recorder	Paper for particulate Silver zeolite or Act. Charcoal for Iodine
Technical Associates	FM-5-ABNI	Scintillator	Iodines	$0\text{-}5 \times 10^5$ cpm	Visual, Audible	Chart Recorder	Silver Activated Charcoal
Victoreen	ARPIGS-1	Various	Particulates and Iodines	$0\text{-}10^2$ µCi/cc	Connected to remote readouts and alarms		Separate Iodine and Particulate Filters
Victoreen	WRGEM-1	Various	Noble Gases Optional Iodines and Particulates	$10^{-7}\text{-}10^5$ µCi/cc	Connected to remote readouts and alarms		Optional

TABLE 6.5. Portable Air Samplers

Manufacturer	Model	Flow Rate	Flow Indicator	Adjustable Flow
Eberline	PAS-1	Dependent on Intake Pressure	Yes	Yes
Eberline	RAS-2	Dependent on Intake Pressure	Yes	Yes
Victoreen	08-030	30 L/m	Yes	Yes
Hi-Q Environ.	CF-900V and CF-950V	2-40 CFM	Yes	Yes
Hi-Q Environ.	CF-50V	2-10 CFM	Yes	Yes
Hi-Q Environ.	STAPLEX	0-70 CFM	Yes	Yes
Hi-Q Environ.	CF-12B	3-4 CFM (12VDC) 7-8 CFM (24VDC)	Yes	No
Hi-Q Environ.	CF-18V	0-6 CFM	Yes	Yes

6.1.6 Analytical Equipment

Analysis of wipe samples, bioassay samples, air samples, and stack samples may be necessary to make accident assessments. This requires equipment capable of accurately analyzing samples over a wide range of contamination levels in a relatively short period of time. Examples of this type of instrumentation are given in Table 6.6. Specific counting systems may consist of gas proportional counters with 2π or 4π geometry or NaI(Tl), GeLi detectors or surface barrier detectors with multichannel analyzers and associated electronics. Other spectrometers, medical dose calibrators, and liquid scintillation counters are often used. Samples may require dilution or partitioning before analysis in order to reduce the activity of the sample. High-level counting systems may require special geometries or collimation with appropriate calibration to accommodate high counting rates. Currently available data analysis systems include computers with appropriate software to reduce counting data into the desired format. The appropriate analytical techniques (e.g., chemical separation, particle filtration, spectrum stripping), are necessary to identify specific isotopes within a sample.

6.1.7 Portable Neutron Monitors

Portable neutron monitors are necessary only when fissile material or neutron sources are present. Currently available, state-of-the-art neutron monitors that claim to accurately measure neutron dose equivalent rate or dose equivalent are described in Table 6.7. Measurements made with different instruments must be interpreted very carefully. The energy dependence, radiation detection efficiency, photon rejection, and angular dependence of the instrument, as well as the exposure conditions present (e.g., neutron energies, interfering radiations, location of radiation source) must be known before the instrument readings can be interpreted correctly or reliably. Generally, exposure conditions are not known before entering the radiation area and the readings of available instruments may be misleading.

6.1.8 Portal Monitors and Hand and Shoe Monitors

This group of instrumentation does not assist in direct accident assessment. However, it is important in the assessment of personnel contamination and control of contamination during and after an accident. These types of monitors may also double as area monitors which indicate the presence of airborne radioactivity. Examples of this type of monitor are given in Table 6.8.

6.1.9 Environmental Radiation Monitors

Environmental radiation monitors are useful in determining radiological conditions at offsite locations. A list of environmental radiation monitors is given in Table 6.9. These instruments normally record the radiation dose rate from beta-photon radiation at a specific location over preselected time intervals. Offsite doses may be calculated from this record. Some monitors are equipped with telemetry and provide instantaneous readouts of remote radiological conditions back to the site. Most, however, require personal attention to collect monitoring data.

TABLE 6.6. Analytical Equipment

Manufacturer	Model	Detector	Radiations Detected α	β	γ	Range
Baird	Centicount 987-514	Gas Flow	x	x	x	0-999,999 Counts
Baird	Polyspec	Gas Flow, GM, NaI	x	x	x	0-999,999 Counts
Nuclear Measurements Corporation	PC-5, PC-55	Gas Flow, Scintillation, GM	x	x	x	0-999,999 Counts
	ACS-7	Gas Flow, Scintillation, GM	x	x	x	
Technical Associates	MST-202	Gas Flow, Scintillation, GM	x	x	x	
Tennelec	LB 5100	Gas Flow	x	x	x	
Ludlum	2600	Proportional, GM, Scintillation	x	x	x	0-999,999 Counts

TABLE 6.7. Portable Neutron Monitors

Manufacturer	Model	Detector	Gamma Insen.	Range	Accuracy	Energy	Weight
Ludlum	15	BF_3 and GM	10 R/h	0-5 x 10^5 cpm			7.5 lb
Nuclear Research Corporation and Victoreen	Snoopy NP-2	BF_3	to 500 R/h	0-2 R/h	±10% of theoretical dose rate	Thermal to 15MeV	25 lb
Victoreen	488A	Boron-lined proportional counter	<500 R/h	0-8 x 10^5 cpm	±10%	Thermal to fast	8.5 lb

TABLE 6.8. Portal Monitors and Hand and Shoe Monitors

Manufacturer	Model	Detector	Radiations Detected α	β	γ	M D L
Berthold	LB 1044	Gas Flow Proportional		x	x	5.5 E-^{6}μCi/cm^{2} (^{60}Co, ^{204}Tl, ^{90}Sr)
Eberline*	PCM-1	Gas Flow Proportional		x	x	0.1 nCi (^{90}Sr - ^{90}Y)
Ludlum	50	GM		x	x	
Ludlum*	40	GM		x	x	
Ludlum*	50	GM		x	x	
Technical Associates	PPM 21 PPM 21A	GM		x	x	
Technical Associates	PPM-23, PPM-23P PFM-23GF PPM-25, PPM-25P PPM-25GF	GM and Gas Flow Proportional Counters		x	x	
Technical Associates	HSM-10A HSM-10AM HSM-10B HSM-10BS	GM	x	x	x	
Technical	HSM-10G	Gas Flow Proportional Counter	x	x	x	

* Denotes hand and shoe monitor.

TABLE 6.9. Environmental Radiation Monitors

Manufacturer	Model	Detector	Radiations Detected α	β⁻	γ	Range
Eberline	EM-1					0-100 R/h
Reuter/Stokes	RSS-111	IC			x	
Reuter/Stokes	RSS-111-100	IC				1 μR/h to 100 mR/h
Reuter/Stokes	RSS-1012	IC			x	1 μR/h to 10 R/h

6.2 VENDOR INFORMATION ON CURRENT INSTRUMENTATION

Information on specifications of currently available commercial instrumentation is discussed in this section. This information was obtained through a questionnaire sent to 25 radiation detection instrument manufacturers and vendors and by a review of commercial instrument catalogs available to the general public. A copy of this questionnaire is included in this report as Appendix B. Approximately 50% of the manufacturers and vendors responded to the questionnaire after follow-up contacts were made.

Data was obtained on instrumentation currently available from a cross-section of manufacturers and vendors. Contacts were made with large and small instrument companies, and companies that specialize in one or two specific types of detectors, as well as or manufacturers that distribute a variety of instruments. The information obtained, though not intended to be all inclusive, should be considered as a thorough cross-section of manufacturers and vendors.

A general description of currently available instrumentation and their capabilities is found in Table 6.10. This listing is for comparison with Table 4.1, which describes the capabilities of instruments currently in use at NMSS-licensed sites. As can be seen, maximum ranges differ by an order of magnitude in some cases.

This difference does not necessarily indicate a deficiency at NMSS-licensed sites. The maximum ranges listed in Table 6.10 correspond to instruments designed for abnormal power reactor monitoring. Regulation Guide 1.97 (U.S. NRC 1981) provides instrument vendors with an incentive to upgrade effluent and area monitors for power reactor applications. This is fortunate because many of the upgraded models may be adaptable to materials licensee use.

It must be pointed out, however, that of the sites observed none identified the need for instruments with such extreme high ranges. The capabilities of the instruments currently available and currently in use appeared adequate for monitoring, either directly or indirectly, the accident condition listed in Table 2.1. Problems identified in this study were generally minor and involved the use and maintenance of emergency instrumentation rather than instrument inadequacies. Recommendations for improved instrument use and maintenance are listed in Section 5.0.

Data on specific instrumentation was summarized in Tables 6.1 through 6.9 of this report. Information was listed for different instruments under the categories of medium to high-range portable exposure and dose rate meters, low to medium-range portable exposure and dose rate and contamination survey meters, portable neutron monitors, facility area, process and criticality monitors, continuous-air monitors, air samplers, analytical equipment, portal monitors and hand and show monitors, and environmental radiation monitors. Similar instrumentation may be available from other manufacturers not listed in these tables. No information under a specification for an instrument means that no data was available in the instrument catalog for that specification and the manufacturer did not offer the information. All instrument specifications

TABLE 6.10. General Instrument Types, Applications, and Measurement Ranges

Instrument Type	Applications	Measurement Ranges
A. Sample Analysis (Analysis of wipe and air filter samples)	1) Gamma spectroscopy systems 2) Gas flow counters for α, β^-, γ 3) Liquid scintillation counters for low energy β^-	Few nCi to several mCi level. Sample dependent upon background and geometry.
B. Portable survey meters (Determination of β,γ, neutron dose rate and α, β^-, γ surface contamination)	1) Small volume (<50 cm^3) ion chambers, mostly nonpressurized for high-rate γ fields 2) Medium-volume ion chambers for mixed β^-/γ radiations 3) Thin window GMs for contamination surveys 4) Gamma insensitive neutron rate meters.	0 - 2.0×10^4 R/hr 0 - 5.0×10^5 cpm (β^-, γ) 0 - 2.0×10^6 cpm (α) 0 - 8.0×10^5 cpm (neutron)
C. Fixed monitoring/alarming (Determination of criticality events and abnormal radiation levels in an area)	1) Multiple ion chamber systems for criticality monitoring (2 of N system, where minimum of 2 detector trips required for alarm) 2) Single ion chamber, GM, or scintillating detector for other external γ field alarming situations 3) Constant-flow air samplers for α, β^-, γ airborne contaminants 4) Passive criticality monitors for post-accident evaluation (require laboratory evaluation).	0 - 10^4 R/hr 0 - 10^5 μCi/cc adjustable alarms with local and remote, visual and audible alarms

listed were obtained from specific vendors or from published catalogs. No attempt was made to verify the manufacturers' specifications or test the instruments.

6.3 FUTURE INSTRUMENTATION NEEDS OF NRC/NMSS LICENSEES

The future instrumentation needs of NRC/NMSS licensees as seen by the manufacturers and vendors and to what extent the manufacturers and vendors expect to meet those needs is discussed in this section. Part of the questionnaire sent to different manufacturers attempted to determine the vendors' attitudes regarding design changes in instrumentation in response to changing monitoring needs.

The following is a list summarizing the responses of the manufacturers and vendors regarding the future instrumentation needs of NRC/NMSS licensees:

- solid state detectors and computerization
- higher quality and more versatile systems using the latest microprocessor technology
- greater use of low-level measurement equipment
- instrumentation with greater reliability and shorter response times
- in-plant electronic repair facilities
- measurement of specific isotopes for more accurate monitoring.

The following is a list summarizing the responses of the manufacturers and vendors regarding the methods and instrumentation they plan to provide to meet the future needs of NRC/NMSS licensees:

- addition of criticality monitors to present systems
- introduction of a new line of monitors using cadmium telluride
- improvements and modification of existing systems to make them more adaptable to various needs
- introduction of a single station area monitor with a wide dynamic range, low and high alarms (audible and visual), battery standby, reference source and remote calibration features
- introduction of solid state neutron detectors to replace scintillation, GM and other detectors for criticality monitoring
- introduction of large-area proportional detectors with micro-computer control as a new generation of high-sensitivity contamination monitors
- introduction of new instruments for measuring working levels of radon daughters in air.

6.4 CONCLUSIONS

The information obtained on the commercial instrumentation currently available to NMSS licensees and other users was obtained through a questionnaire sent to manufacturers and vendors and by a review of commercial instrument catalogs. The information obtained was not intended to be all inclusive but should be considered to be from a thorough cross-section of manufacturers and vendors.

The capabilities of the instruments currently available and in use at NMSS licensees appear to be adequate for monitoring accident conditions. In general, the problems identified in the site visits were minor and pertained to the use and maintenance of emergency instrumentation and not inadequacies of the instruments.

The responses of the manufacturers and vendors regarding the future instrumentation needs of NRC/NMSS licensees and the methods by which they will be met show that: 1) there are some manufacturers that are sensitive to or at least knowledgeable of NRC/NMSS requirements and future needs, and 2) that some manufacturers plan to improve or modify existing systems or to introduce completely new systems to meet those needs. Most of the improvements involve the incorporation of computerized systems for data analysis and control or new types of detectors

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APPENDIX A

EXAMPLES OF SPECIFIC EQUIPMENT OBSERVED DURING SITE VISITS

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EXAMPLES OF SPECIFIC EQUIPMENT OBSERVED DURING SITE VISITS

CLASS I

Low-Volume Air Samplers for Gaseous Materials

1. Victoreen (08-030)
2. Eberline (RAP 1 or RAS 2)
3. RADECO (AVS-28)

High-Volume Air Samplers for Particulate Materials

1. Johnson (ST-4)
2. Victoreen (08-600)
3. Eberline (RAP 1 or RAS 2)
4. RADECO (AVS-60)

Analytical Equipment

1. Baird, Canberra, and Tennelec Spectrometers modification
2. Various analyzers using gas flow or scintillating detectors
3. Medical dose calibrators

Criticality Alarms

1. Nuclear Measurements (GA-3M)

Contamination Monitors

1. Technical Associates (PUG-1)
2. NICO (MD-3)
3. Ludlum (3, 28A)
4. Nuclear Chicago (?)
5. Eberline (PAC-4G, 3A, 15)

High-Range β /γ Meters

1. Eberline (PIC-6A)
2. Victoreen (470A or 471A)

High-Range Neutron Rate Meter

1. Victoreen (488A)
2. Eberline (PRS-2P/NRD)

CLASS II

Portable Air Samplers

1. Eberline (RAP 1 or RAS 1)
2. RADECO (AVS-28 or AVS-60)

Fixed-Alarm Air Samplers

1. Victoreen "XenAlert"
2. Triton (133C) (Xenon Monitor)
3. Triton (955B)
4. Johnson (TR-5)
5. RADECO (GM-222)

Contamination Monitors

1. Baird (904-122)
2. Johnson (GSM-10) (RML-3)
3. Ludlum (12) (14C)
4. DCA (3007)
5. Victoreen (493) (496) (491) (498)
6. Eberline (E120) (E120E) (520)

High-Range Rate Meter

1. Eberline (PIC-6A)
2. Victoreen (740A) or (471A)

Analytical Equipment

1. Various analyzers with gas flow or scintillating detectors
2. Medical dose calibrators

CLASS III

Low-Volume Air Sampling (low-flow rate pumps for bubbler system)

1. Eberline (RAS 1) (RAS 1Q)
2. Victoreen (08-430)
   Personal air sampler

Alarming Air Samplers

1. Johnson (TR-5)
2. Triton (955B)

Contamination Monitors (except H-3)

1. Baird (904-122)
2. Johnson (GSM-10) (RML-3)
3. Ludlum (12) (14)
4. DCA (3007)
5. Victoreen (493) (496) (491) (498)
6. Eberline (E-120) (E-120E) (E520)

Analytical Equipment

1. Liquid scintillation counters
2. Gas flow detector and counter

CLASS IV

High-Rate Monitors

1. Eberline PIC-6A
2. Victoreen (470A) (471A)

Low-Range Survey Meters

1. Ludlum (19)
2. Eberline (PRM-7)

Analytical Equipment

1. Gas flow or scintillating detector and analyzer

APPENDIX B

QUESTIONNAIRE SENT TO
VENDORS AND MANUFACTURERS

QUESTIONNAIRE

The following questions pertain to instrumentation capable of monitoring radiological conditions during accidents at NMSS-licensed facilities.

1. What instruments do you currently have available that are adequate to monitor and measure accident radiological conditions? Please send specifications of instruments that measure beta/gamma dose rate fields and surface contamination. Also of interest are instruments for the collection and analysis of airborne activity, alarming effluent and area monitors, and criticality monitors.

2. Do you forsee any changes in the monitoring needs of materials facilities in the future?

3. In the near future, does your company have plans to develop and market any new lines of equipment in response to changes in monitoring needs?

4. If so, please provide information (specifications) on any significant instrument development or modification underway at this time to meet projected needs.

5. How are instrument specifications determined (e.g., determined through testing or theoretically derived)?

6. What supplemental sources (exclusive of factor specifications) on instrument performance and operation are available to the customers?

7. Are operating instructions for emergency and high-level use provided with your equipment?

8. Are your instruments calibrated at your facility or elsewhere?

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This report provides a brief review of emergency radiological monitoring instrumentation capabilities based on visits to Nuclear Material Safety and Safeguards (NMSS) licensees and on a review of the open literature. Recommendations based on findings are made with regard to instrument design and operation, training, calibration, testing, analytical methods, sampling procedures, and quality assurance. An assessment of currently available instrumentation is made with respect to types of instruments, instrument specifications, and the future needs of NRC/NMSS licensees as seen by instrument manufacturers and to what extent those needs will be met.

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