Technologies for Detection of Emissions | 3

Detecting the emissions discussed in the last chapter requires a variety of techniques. The samples must be collected from carefully selected locations using procedures to prevent cross-contamination. They must then be transferred to the analytical laboratory. Many different lab instruments are available. Selecting the instruments to be used depends on the type of sample, the materials that might be found in it, the precision needed for the answers, and other factors. Then the results must be interpreted.

This chapter starts with a description of environmental monitoring as used in Iraq, the first public demonstration of its value. Then it describes the various steps that constitute environmental monitoring. Progress in making environmental monitoring a routine part of IAEA safeguards is discussed in the next chapter.

THE IRAQI EXPERIENCE

The agreement ending the Gulf War included Iraq's acceptance of United Nations inspection of all facilities suspected of contributing to a nuclear weapon capability. Within six weeks, inspectors from the International Atomic Energy Agency arrived to begin an exhaustive, and at times dramatic, survey of Iraq's nuclear weapon facilities.

Much of the equipment and materials had been hastily removed and hidden during the war and the month following, so the inspectors used means other than conventional materials accountancy and equipment examination to detect activities. Hundreds of samples were collected and sent to various labs for analysis. Many of these samples were quite nontraditional. Inspectors took smears from the surfaces of equipment and from the buildings themselves. They also collected samples of soil, vegetation and water outside the buildings. The first eight inspections in 1991 produced 464 samples of non-nuclear materials.[1] The first set of analyses of samples provided information to guide subsequent sampling. It was important to get the results of the analyses rapidly so that subsequent inspections could be designed to build on that information.

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[1] Including samples of construction materials such as concrete and steel, which are not considered part of environmental monitoring. D.L. Donohue and R. Zeisler, "Behind the Scenes: Scientific Analysis of Samples from Nuclear Inspections in Iraq," *IAEA Bulletin*, January, 1992.

The analyses were performed by the IAEA itself and at labs in several member states, including the United States. The IAEA has two labs at Siebersdorf, Austria: the Safeguards Analytical Laboratory (SAL) and the Physics, Chemistry and Instrumentation (PCI) Laboratory. SAL, the prime safeguards laboratory, analyzes nuclear materials for uranium and plutonium content and isotopic composition. PCI uses a different set of techniques to analyze for radionuclides and other elements in the environment; much of its work has been on the International Chernobyl Project.[2] Specific techniques are discussed in the following sections. The analyses for the Iraqi samples are listed in table 3-1.

The most surprising result of the analyses was the discovery of isotopically altered uranium which did not match any known (declared) materials. Iraq was not known to have any enrichment capability at all, making any evidence of enrichment a surprise. That surprise was greatly compounded with the discovery of extremely depleted uranium (i.e., with a very low fraction of U^{235}) that could only have been produced with electromagnetic or laser separation techniques— techniques not known to be in commercial use

TABLE 3-1: Samples from Iraq Processed at IAEA Laboratories in 1991

Inspection	Non-nuclear materials	Nuclear materials
1st	48	31
2nd	35	0
3rd	139	51
4th	41	0
5th	49	61
6th	7	0
7th	139	141
8th	6	105
Total	464	389

Measurements requested

Sample category	Sample types	Analyses requested
Non-nuclear materials (Environmental)	Smears Vegetation Soil Debris Rocks, Ores Water	Presence of U, Pu, or radionuclides Amount of U, Pu Presence of F, Cl U, Pu isotopics Presence of high explosives
(Materials of construction)	Graphite Steels Beryllium Unknown metals	Purity, type or identity
Nuclear materials	Uranium metal Uranium compounds Plutonium compounds Polonium U, Pu waste and scrap	Amount of U, Pu U, Pu isotopics Amount of polonium Compounds of U, Pu Trace elements in U compounds

SOURCE: D.L. Donohue and R. Zeisler, "Behind the Scenes: Scientific Analysis of Samples from Nuclear Inspections in Iraq," *IAEA Bulletin*, January 1992.

[2] D.L. Donohue and Rolf Zeisler, "Analytical Chemistry in the Aftermath of the Gulf War," *Analytical Chemistry*, 1993, 65,359A-368A, American Chemical Society.

anywhere in the world. As discussed in chapter 2, the only commercial-scale enrichment technologies—gaseous diffusion, centrifuge, and advanced vortex tube—discharge depleted uranium with tails of about 0.3 percent U^{235}. No one believed that Iraq was ahead of western developers of laser enrichment, but it still took a while for experts to accept that anyone would use such an old, energy-inefficient technology as electromagnetic separation.[3] After three inspections the evidence from sample analysis and other means was compelling, and Iraqi officials were forced to reveal the EMIS program. Enrichment equipment had been operated at Tarmiya and Tuwaitha, and additional facilities were under construction at Ash Sharkat. When calutron components themselves were recovered and materials analyzed, uranium in one sample was found to have only 0.06 percent U^{235}.[4]

Other analyses also disclosed undeclared irradiation of uranium to produce very small quantities of plutonium. However, this activity, detected by analyses of conventional nuclear material samples, was a minor part of the Iraqi program. In addition, uranium from three different ore bodies was discovered, including indigenous production as a byproduct from an Iraqi phosphate plant.[5]

Environmental monitoring was used to verify the accuracy of the final Iraqi declarations. It is still used to verify that no covert nuclear material production is underway. In particular, wide-area monitoring of waterways is performed, yielding a high probability of detecting any significant production of plutonium.[6] The IAEA takes water, sediment, and biota (plants and animals) samples at 50 river stations in Iraq every two years. The IAEA does not maintain air monitoring stations because of the expense. It is, how-

ever, considering air particulate samplers mounted on its vehicles. These would direct air through a filter as the vehicle moves, collecting dust and other materials. This is a promising approach in Iraq because the agency has many vehicles and access everywhere. Car engine air filters have also been used as collectors. Other forms of environmental monitoring, such as the collection of soil and plant samples, are still being performed to verify compliance with agreements. On the average, one IAEA inspector is in the field every day in Iraq.

Early problems in the Iraqi environmental monitoring program have largely been overcome. Contamination ruined some samples. The trace quantities characteristic of environmental samples can be contaminated by exposure to almost any source of radionuclides. For example, one scientist from a U.S. national lab apparently left tiny particles of nuclear materials from his home lab at several sites, giving erroneous readings when they were unknowingly collected with the environmental samples.[7] Greater attention to cleanliness and double bagging of samples has been important. In addition, contamination from Chernobyl, especially cesium-134 and -137, was measured in Iraqi samples and had to be taken into account. Even natural uranium created problems. One building was made of concrete that had 25 parts per million of uranium, a level close to minable ore quality.[8]

SAMPLING

The collection of samples is conceptually simple, but there are some complicated aspects. The object is to collect gaseous, particulate or liquid emissions from a covert nuclear operation. The intent could be to determine if undeclared activi-

[3] Anthony Fainberg, *Strengthening IAEA Safeguards: Lessons from Iraq*, Center for International Security and Arms Control, Stanford University, April 1993, pp. 11–15.

[4] Since this sample was found on the collector of a calutron, it was not the result of environmental monitoring. See D.L. Donohue and R. Zeisler, "Behind the Scenes: Scientific Analysis of Samples from Nuclear Inspections in Iraq," *IAEA Bulletin*, January 1992.

[5] Personal communication with IAEA staff, Apr. 3, 1995.

[6] Personal communication with IAEA staff, Apr. 4, 1995.

[7] Ibid.

[8] Ibid.

ties are taking place at a declared facility, or to search for an undeclared facility. As practiced so far by the IAEA, sampling has mainly been conducted at declared facilities. The most important technique has been taking swipes from equipment or other surfaces in the targeted facility. Swipes (or smears) are simply pieces of cloth or paper (kept scrupulously clean to avoid contamination) which are wiped on the surface and stored in a plastic bag. Wiping picks up particles that have settled on the surface. Even thorough washing of surfaces is unlikely to remove all the particles, and inspectors learn where to find the optimum places to take swipes. The swipes need not be taken directly in the process area to detect what activities took place there; common areas and adjacent rooms collect enough telltale particles also, carried in by personnel, equipment, or by air currents.[9]

Taking swipes inside a facility is the most effective technique of environmental monitoring. It is a powerful tool that is generally unavailable to national intelligence efforts, which normally do not have such facility access.

Outside the plant, sampling can still involve swipes, for example on window ledges, signs, or shiny leaves such as aloe. However, it is often easier to simply pick the leaves or other parts of the plants. Pine needles are good collectors because they have a sticky residue that is particularly likely to hold particles. Not only do plants (biota) capture particles that have settled on their surfaces, but they also collect soluble material carried to their roots in groundwater. Thus biota act as integrators of emissions over periods of weeks to years. Grazing animals can also collect particles, which are concentrated in their excrement.

Similarly, soil near the surface can be collected. Particles settle from the air and can remain on the surface for many years.

Air samples, either gaseous or particulate, can be taken either at stationary sampling stations or from vehicles traveling in suspected areas. If the plume from the facility is caught, very accurate and timely information can be gleaned. Gaseous plumes can, under some conditions, be detected for hundreds of miles. There are several problems with gas and particulate sampling, however. First, some emissions from nuclear activities occur in puffs rather than on a continuous basis. For example, when a reactor is opened for refueling, or a batch of spent fuel is chopped to extract the plutonium, gaseous emissions occur briefly. Second, the movement of the plume can be very erratic, depending on local winds. Thus the network must be fairly dense to have a high probability of capturing the signatures. Not only is such a network expensive to construct, but the stations need to be visited frequently to collect samples or otherwise service the equipment. The dense network required with different sampling techniques for gases and particulates, their maintenance, and particularly the laboratory analysis of the large number of samples required add up to a very large operating expense. Furthermore, once a plume is detected, it must be attributed to a source. This requires a meteorological database as well as models to analyze the transport and dispersion of effluents.

Emissions can get into water from liquid runoff from the facility, by settling out onto the ground and getting washed away by rain, or by settling directly into the water. Holding ponds are particularly desirable as sources because they catch the runoff directly. There are two techniques for sampling water. One is to just fill a bottle. The other is to pump water through a filter to collect suspended material or an absorber to collect soluble or colloidal species. Lakes, small streams, rivers, and seas/oceans are all possible sources, though oceans tend to dilute the signal rapidly due to mixing.

A related collection medium is sediment in a river or the ocean, which can be dug up and bagged. Sediment can accumulate over a long period of time, providing a record of what came down river over time. It is tricky to select a rep-

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[9] Personal communication with IAEA staff, Apr. 3, 1995.

resentative deposit; depending on the river flow pattern, a specific piece of sediment could be a single recent deposit or an old one with no recent material. In either case, the sediment could be deposited when no nuclear material was present even though at other times it was present. Collecting water plants is another option, as with terrestrial plants. One advantage of water as a source is that it is much easier to trace a detected substance up-river than up-wind. Whereas winds change, the watershed remains fixed.

Construction materials, while not literally a source for environmental sampling, are also considered because the same analytical techniques can be used on them. Moreover, they are likely to be collected along with environmental samples as part of the IAEA's upgrading of safeguards. Steel and other materials from a reactor can carry considerable information on the operation of the reactor. Even analysis of unirradiated material can be useful as with, for example, steel pieces in Iraq that had been thought to be parts of centrifuges for enrichment, but which were shown not to be maraging steel, a material critical for centrifuge rotors.

A careful plan is needed to know where and how to sample to have the greatest chance of finding telltale emissions with a minimum of effort. Inspectors cannot simply arrive at a facility and start collecting samples. For example, if prevailing winds blow consistently in one direction, there is little point in sampling intensively upwind. If an HEU plant is suspected, tritium or noble gases are unlikely to be emitted, so gas sampling will serve little purpose. The plan must take into account the type of suspected activity, the terrain, local vegetation, weather patterns, funds available for analysis, and other factors.

Once collected, the samples are double-bagged to prevent contamination, and sent to the IAEA's laboratories which protect the samples from particle contamination. A clean room is being built there with U.S. assistance. The clean room, which will have carefully controlled and filtered ventilation, will contain the shipping area, storage areas for sample archives, and analytical instruments. The requirements for the clean room far surpass anything the IAEA has had to construct in the past, because environmental samples contain so much less critical material than do the traditional safeguards samples of process materials. It is critical to avoid cross contamination.

ANALYTICAL INSTRUMENTS

A broad range of analytical techniques is needed for light and heavy radionuclides with different modes and rates of decay (see box 3-1), inorganic chemicals, and organics. The specific analytical technique chosen for a sample depends on the type of sample, the signature suspected, accuracy required, the rapidity with which results are needed, and costs. Samples may be divided and tested by several means. As environmental monitoring becomes routine, the IAEA will archive samples, or parts of them, to establish a baseline that can be compared with anomalies discovered in the future, perhaps with more sensitive instruments.

The major categories of analytical lab instruments are:

- Radiometers (counters) which measure the type and intensity of radioactive decays (alpha particle, beta particle, gamma ray).
- Spectrometers to characterize the radiation emitted by decaying or excited atoms; may be combined with counters.
- Mass spectrometers, that separate isotopes according to their different masses and measure their relative abundance (i.e., they derive a spectrum of masses). Several technologies may be combined with the mass spectrometer to improve sensitivity.
- Microscopes and electron microscopes, for examination of particles.
- Traditional chemical instruments such as titration or chromatography apparati, which determine which chemicals are present and their concentration.
- Specialized instruments such as lasers and reactor irradiation for activation analysis.

BOX 3-1: Radioactive Decay

Radioactive nuclei spontaneously decay (break up), emitting observable radiation and transmuting themselves into other nuclei. This process continues until a stable form is reached. Transmutation can be accomplished by the emission of alpha rays (helium nuclei), or beta rays (electrons or positrons), or by the absorption (capture) of an orbiting electron. Gamma rays and x-rays, which are part of the electromagnetic spectrum that includes visible light, may also be emitted, but this changes only the energy level, without itself causing transmutation.

Only the heaviest nuclei emit alpha particles. These are mainly actinides, elements of atomic number 89 (actinium) and higher. Uranium (92) and plutonium (94) are actinides. Alphas are emitted with characteristic energies that can be measured accurately to identify the isotope of origin. Alpha spectrometry is used to characterize nuclear weapon material.

Isotopes lighter than actinides that indicate nuclear reactor operation are fission products (from the fissioning of nuclear fuel) or activation products (non-nuclear materials such as fuel cladding or reactor components that have absorbed neutrons). These usually have excess neutrons, and so decay by emitting electrons (positron emission or electron capture occur in nuclei that have too few neutrons). The beta particles emitted by a given isotope range in energy from zero to a characteristic maximum. Measuring the energy of a given beta particle gives very little information about its source, although a spectrum or collection of beta particle energies can be used to identify a particular beta emitter. Thus, substances such as tritium (hydrogen-3, which has an unusually low-energy beta) can be measured by a combination of chemistry and beta spectrometry.

Each decay carries with it a characteristic pattern of gamma rays and x-rays. In many cases, gamma-ray spectrometry can identify an isotope by measuring the energies and relative abundance of the gammas it emits. However, many isotopes do not emit an identifiable spectrum; the spectral lines can be too weak or so myriad that a pattern cannot be identified. Also, the "fingerprints" of different isotopes overlap, so that an abundant constituent can mask a rare one. Experience is needed to understand the cases where gamma rays yield useful information.

SOURCE: Office of Technology Assessment, 1995.

Some of the most important instruments that can be used to analyze environmental monitoring samples are described here. Microscopes and conventional chemical techniques, such as are already used for safeguards materials analysis, are not included.

Gamma-ray spectrometry—measures energy of gamma rays from radioactive decay. Each decay has a specific energy level(s) which may be identified easily. This method is used for screening samples as it is quick and requires no elaborate preparation. It also can identify a broad range of isotopes, including fission products (e.g., cesium-134 and -137, ruthenium-106), activation products (e.g., cobalt-60), and actinides (e.g., uranium-235, plutonium-239, and americium-241). It does not require isotope-specific preparation, and can be used for any of the environmental samples discussed above. Sensitivity can be high; short half-life isotopes can be identified from samples containing only thousands of atoms.

Alpha-particle spectrometry—measures the energy spectrum of alpha particles emitted by plutonium and other actinides so that the isotopes present can be identified by their characteristic energy levels (similar to the gamma-ray spectrometer). This technology can measure the ratio of uranium isotopes in a 1 microgram sample, providing useful information as discussed below. Plutonium can also be detected in amounts less than one nanogram.

Beta spectrometry—a counter for beta decay. The emitted beta particles (electrons) are

directed through a fluid. In a liquid scintillation counter, fluid molecules struck by particles are excited and emit flashes of light. The liquid scintillation counter is used to measure strontium-90, an important fission product that can be released during reprocessing. Tritium is measured by gas proportional counters, which produce current pulses whose magnitude is proportional to the energy of the incoming beta particle.

Neutron activation analysis—the sample is irradiated with neutrons from a reactor or other source to generate radioactive isotopes. Then the gamma ray spectrum lines are measured to identify the radioisotopes; the intensities of the gamma emission lines indicate the concentration. The process can be automated and rapid. It is especially good for iodine-129, technetium-99 and elemental fluorine.

Delayed neutron counting—the sample is irradiated with neutrons. Fissioning isotopes (U^{235} or Pu^{239}) emit more neutrons, but not all at the moment of fissioning. Some are delayed for a matter of seconds. Counting the delayed neutrons gives a measure of the fissile isotopes present. Nanogram quantities of uranium or plutonium in the sample can be measured.

X-ray fluorescence (XRF)—the sample is stimulated by X-rays, gamma rays, or energetic particles to produce fluorescent emissions. Emissions from elements ranging from sodium to the heaviest elements of the periodic table can be measured and identified by comparison to standards for the various elements. This technique is used for rapid screening of samples. It identifies chemical elements—and is good at detecting metals, including uranium and plutonium—but it does not differentiate among isotopes of the same element.

Laser fluorimetry—the sample is ashed (burnt or oxidized under controlled conditions to remove combustibles and preserve the noncombustibles) and dissolved in hot nitric acid. It is then illuminated with an ultraviolet (UV) laser

and any fluorescence measured. Many uranium compounds fluoresce, and this instrument can measure them with high sensitivity and accuracy.

Inductively Coupled Plasma Mass Spectrometry (ICPMS)—the sample is atomized in a high temperature plasma and directed into a mass spectrometer. Once inside, the atoms pass through a magnetic field which forces them to move in a curve, with the lighter atoms curving more sharply than the heavier ones. This separation allows them to be collected separately and measured, permitting their identification. ICPMS can measure nanogram-quantities of uranium or plutonium with good accuracy. For example, the uranium-235/238 ratio of a sample with several tens of nanograms of uranium can be measured with 2 percent accuracy.[10] The procedure is rapid and requires no elaborate preparation. It is particularly good for water samples because the suspect material must be in solution anyway. Over 70 elements can be surveyed.

Thermal Ionization Mass Spectrometry (TIMS)—the sample is ashed and the residue (or just a particle) is attached to a filament. The filament is heated by an electric current to a high temperature, which vaporizes the sample. The vapor is ionized and the ions directed into a mass spectrometer, as with the ICPMS. The TIMS technique can detect small deviations from natural isotope ratios. It is the most accurate instrument in common use to measure uranium and plutonium composition and is especially valuable for low concentration samples (e.g., nanograms per liter). TIMS is more accurate than ICPMS, allowing the detection of more dilute samples. The ratio of uranium 235 to 238 can be measured to at least 0.5 percent accuracy.[11] However, the cost can be several thousand dollars per sample, about 2 to 5 times higher than that of ICPMS.

Accelerator Mass Spectrometer (AMS)—uses a particle accelerator as input to the mass spectrometer to achieve greater separation. This

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[10] Personal communication with Philip Miller, Lawrence Livermore National Laboratory, Mar. 1, 1995.
[11] Ibid.

is the most sensitive instrument currently available, and relatively few labs have one. It can be used to measure small changes in the concentration of naturally occurring but rare radioisotopes with long half-lives (e.g., carbon-14 and iodine-129, which are created by cosmic rays as well as by nuclear activities). AMS can detect isotopic concentrations of 1 atom in 10^{15}, making it excellent for trace samples collected far from the emitting site.[12]

BULK AND PARTICULATE ANALYSIS

Once a sample is collected, it can be examined in two major ways. First, the entire sample (or just a portion) can be tested using one or more of the instruments discussed above. This is called bulk analysis. Not only the radioactive or chemical material sought, but the medium (e.g., soil, vegetation) and sometimes the collecting agent (swipes, filters) are tested. Bulk analysis reveals information about average properties of the sample and indicates the presence of anomalous components.

Alternatively, suspect particles themselves can be isolated and analyzed. A swipe of a dirty piece of equipment can collect many thousands of particles, so identification of the relatively few interesting ones can be difficult. The method used by the Air Force Technical Applications Center (AFTAC) laboratories is to extract the particles from the sampling media (swipe), attach them to a clear plastic (Lexan) and irradiate them in a nuclear reactor. Uranium and plutonium atoms fission during irradiation and leave tracks in the Lexan. When viewed under a microscope, the particles that produced the tracks can readily be identified and isolated.[13]

Individual particles can be examined optically and with an electron microscope, and then tested by TIMS or other mass spectrometers as discussed above. Much can be learned visually by a trained observer. In fact, Russian particle analysis is largely based on intensive visual inspection. This is a very different approach from U.S. analytical techniques and can discover different things about a particle.[14] The morphology, or structure of a uranium or plutonium particle bears information as to how it was formed. For example, a particle of uranium might contain UO_2, U_3O_8, and U_4O_9 in various structures, depending on the temperature at which it was formed. That indicates the process that was used. A scanning electron microscope (SEM) is used to provide a preliminary analysis, such as whether the particle is crystalline or amorphous, and whether other materials are embedded in the particle.

Particle analysis is considerably more labor intensive and costly than bulk analysis. Thus it is used only where extreme sensitivity and precision is needed. In the IAEA field trials, bulk and particle analysis yielded approximately the same results when samples rich in particles were directly compared. Thus the two approaches complement each other, serving somewhat different purposes.

DATA INTERPRETATION

The information produced by the techniques described above cannot be expected to unambiguously define whatever activities have taken place. It may be conclusive, as when HEU is found in a variety of samples at a LEU plant. Most activities, however, can be concealed sufficiently that only some samples will have any indications, and these may be inconclusive. A few particles of plutonium do not guarantee that reprocessing is taking place, as they may be fallout from the Chernobyl accident or weapons testing, or contamination from a legitimate research center. Analysts must be experienced with the operations that could have produced them, and

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[12] Ibid.

[13] Personal communication with Peter Aldred, Advanced Nuclear Applications (AFTAC analytical lab), Vallecitos Nuclear Center, Mar. 2, 1995.

[14] Personal communication with IAEA staff, Mar. 31, 1995.

the tools, such as burn-up computer codes, that can be used to understand the possibilities. In addition, they must know how much data is required to reach conclusions, and how reliable the data must be. Further sampling and analysis may have to follow the first indication to determine if it was an isolated anomaly or truly indicative of illicit operations.

Reaching conclusions on the existence of undeclared activities is likely to require a multi-dimensional analysis, of which environmental monitoring will be only one part. Environmental monitoring itself will make a strong case if several different signals (as discussed in chapter 2) can be verified, especially for reactor operation and reprocessing. Uranium and plutonium isotopes, perhaps in conjunction with other actinides, are a good indication of reprocessing. Finding other radionuclides such as fission and activation products, and chemicals such as tributyl phosphate, would greatly strengthen the indication. Finding tritium in waterways or the air strongly suggests reactor operations.

As has been noted above, even minute traces of radioisotopes can be detected. With the more sensitive instruments, a few million atoms of uranium can be sufficient for measurement and a few billion can determine the full isotopic fingerprint, as shown in table 3-2. The ratio of certain isotopes can yield valuable information. For example, the ratio of uranium-234 to -235 can indicate the type of enrichment that was used. The bigger the sample, the more information that it yields. With a sample containing 0.1 to 1.0 grams of plutonium (implausibly large for an environmental monitoring sample, but easily available from conventional safeguards or a smuggling case), an analyst may be able to tell the date of separation from spent fuel; the method of casting; irradiation time; the original enrichment; and the reprocessing technique.[15]

The lab information must be analyzed by an experienced analyst to extract the appropriate conclusions. What are the possible sources of the

TABLE 3-2: Measurement Sensitivities (TIMS)		
Element	Detection	Isotopic analysis
U	5×10^6 atoms	5×10^9 atoms
Pu	5×10^5	5×10^8
Am	2×10^5	2×10^8
Np	2×10^5	2×10^8

SOURCE: Don Rokop, Los Alamos National Laboratory, 1995.

isotopes or chemicals found? How consistent with these sources are the forms of the discovered substances? If the suspect activity is taking place, what else should be found? How long, and at what scale, has it been taking place? Is additional sampling necessary to confirm these findings, and what sort of sampling should it be?

This information also must then be analyzed on a country- and site-specific basis before any accusations can be made. What other activities are known to be taking place? Is the country capable of mounting this kind of operation? What other indications (e.g., imports of equipment, movement of technical personnel) support or contradict the conclusions? Are the topography and local weather patterns of the suspected site consistent with finding samples where they were found?

Analyzing large numbers of environmental samples will generate huge amounts of data. Keeping track of all the data will be difficult. Adequate provisions must be made for computers and software to handle, process, and store the information.

CONCLUSIONS

The analytical techniques described in this chapter can detect and characterize routine emissions from nuclear facilities. They are sufficiently sensitive to have a high probability of detecting covert activities to produce nuclear weapons materials if the sampling is close to the facility. Long-distance monitoring, especially of the air, is more problematical. The more dilute the emissions become, the less likely that critical

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[15] Personal communication with Sid Niemeyer, Lawrence Livermore National Lab, Mar. 1, 1995.

materials can be distinguished from background, or that they can be traced back to the source. Sampling and analysis will improve over the next few years as the IAEA becomes more experienced and uses already available, more sensitive equipment. Technologies under development may improve analytical capabilities, as discussed in chapter 5.