NIST Ionizing Radiation Safety Committee

Initial Report of Plutonium Contamination at NIST Boulder

July 30, 2008

Table of Acronyms

Acronym	Name
CFR	Code of Federal Regulations
CRM	Certified Reference Material
DOC	Department of Commerce
DOE	Department of Energy
DOT	Department of Transportation
EEEL	Electronics and Electrical Engineering Laboratory
EMSS	Engineering, Maintenance, Safety and Support
HP	Health Physicist
IRSC	Ionizing Radiation Safety Committee
LANL	Los Alamos National Laboratory
MASC	Mountain Area Support Center
MSDS	Material Safety Data Sheet
NBL	New Brunswick Laboratory
NIST	National Institute of Standards and Technology
NMMSS	Nuclear Materials Management and Safeguards System
NRC	Nuclear Regulatory Commission
OSHE	Office of Safety, Health and Environment
PANDA	PAssive Non-Destructive Assay
RAP	Radiological Assistance Program (DOE)
RIS	Reporting Identification Symbol
RSO	Radiation Safety Officer
SHED	Safety Health and Environment Division
SNM	Special Nuclear Material
SOS	Safety Operational System
SQUID	Superconducting Quantum Interference Device
SRM	Standard Reference Material

Key Participants Identified in Report

Worker 1	Researcher who worked on the detector project with the plutonium sources.
Worker 2	Researcher who worked with Worker 1 on project providing computer support. Worker 2 did not handle the plutonium sources.
Worker 3	Researcher with past radiological training and experience who worked with Workers 1 & 2 on experimental procedures, but was not present in the lab on June 9.
Principal Investigator (PI)	Leader of the detector research program and the one who could authorize persons to use the source under the Boulder NRC license.
Project Leader	Quantum Sensors Project Supervisor for the PI. The project leader is also a NIST Fellow.
Division Chief	Chief of the Quantum Electrical Metrology Division and supervisor of the Project Leader.
Boulder Radiation Safety Officer (B-RSO)	Health physicist with Radiation Safety Officer responsibilities described under the Boulder NRC license.
Health Physics Group Leader (HP-GL)	The Certified Health Physicist, Leader of the Health Physics Group in the Safety, Health, and Environment Division (Based in Gaithersburg).

I. Introduction

On June 9, 2008, a release of a plutonium compound (plutonium sulfate tetrahydrate) occurred at the NIST Boulder laboratories, which subsequently contaminated several locations and personnel in those locations.

On June 12, 2008, the NIST Deputy Director asked the NIST Ionizing Radiation Safety Committee (IRSC) to conduct a review into the circumstances and actions leading up to, including, and following the contamination event. The review was to include an examination of NIST's authorization, control, and oversight of work using the plutonium compound, and the NIST response to the incident. The IRSC was asked to:

1. Identify the cause(s) of the incident and any contributing factors;
2. Evaluate the NIST response to the incident; and
3. Recommend the following: (a) corrective actions; (b) methods to avoid future incidents; and (c) ways to improve safety performance and incident response.

This report is an initial review report and covers our findings and recommendations related to the circumstances leading up to, including, and immediately following the contamination event. Subsequent phases of our review will examine actions taken later in the event and will look at the overall effectiveness of the NIST response. We will also reevaluate findings and recommendations reached in this initial report as new information becomes available. As part of this phased approach, we will identify additional information or analysis needed to complete our review and will develop, in consultation with the NIST Deputy Director, a timeline and process to prepare and submit a final report. Prior to releasing a final report, the IRSC may release additional interim reports if they are deemed necessary to share important findings or conclusions from the ongoing review process.

This report is organized as follows:

I. Introduction
II. Review process
III. Relevant background information
IV. Summary description of event
V. Analysis
VI. Findings
VII. Recommendations

Appendix A Detailed chronological description of event

II. Review Process

Very generally, an incident of this type and the incident response can be viewed as occurring in several distinct phases:

1. Precursor actions and conditions;
2. The event(s);
3. Crisis management phase; and
4. Consequence management phase.

NIST is continuing to respond to the plutonium contamination event in Boulder, and it remains an ongoing and evolving situation. Even today, more than one month after the initial contamination incident, responders continue to assess, control, and take corrective actions to protect personnel and develop plans to remediate affected facilities. A complete review of an incident of this type requires the investigation to cover all phases of the incident and the associated response. However, the need for investigators to get early access to the event site and to the involved personnel in order to obtain fresh information must be balanced against the requirement that these actions not hamper the ongoing response. One method to achieve this balance is to use a phased investigation process. This type of process combines a preliminary on-site investigation to obtain information about the circumstances surrounding the event with the crisis management phase of the response. This is the time when information is most volatile and liable to change or be lost. Subsequent phases of the investigation and review focus on the consequence management phase and include an examination of new information learned about earlier phases of the event.

The IRSC adopted this type of phased approach to conduct this review. We sought to maximize the amount of information collected from the incident while minimizing the impact on the ongoing response. We decided to base our initial review on two primary but independent sources of information:
(1) The internal investigative findings from NIST personnel directly involved with or responding to the contamination event, and
(2) The findings from a separate investigation conducted by external experts selected for their expertise and ability to provide both broad perspective and critical analysis.

The following is a brief summary of major steps in the review process:

A. On June 12, the Chair of the IRSC requested that participants in the event (all persons identified as being in the area of the lab during and immediately after the contamination event) be asked to provide independent, written statements with their detailed recollections of their actions during the contamination event. These statements were given to the IRSC beginning on June 19.

B. On June 13, NIST Chief Scientist Rich Kayser directed the NIST Safety, Health, and Environment Division (SHED) to lead the response to the incident. Upon the request of the IRSC Chairman, he also charged SHED with preparing an initial incident report of the events surrounding the contamination event. A preliminary report was provided on June 19. The preliminary report was updated as needed through July 1.

C. On June 11, EEEL initiated an internal review of the incident in accordance with its own policy. On June 24, the IRSC Chair asked EEEL management to share all results of any internal EEEL management reviews of the incident with the IRSC. EEEL submitted an incident review report to the IRSC Chairman on June 30.

D. On June 22, NIST appointed five external experts to Special Government Employee positions in order to conduct the external review. The experts were selected and invited by the IRSC Chair based on their experience, expertise, and ability to provide critical, independent judgment to the review. These experts are listed below.

Paul S. Hoover
Senior Advisor, Radiation Protection Division, Los Alamos National Laboratory

Lester A. Slaback, Jr.
Former Supervisory Health Physicist, NIST (retired in 2001)

Kenneth C. Rogers
Former Commissioner, Nuclear Regulatory Commission (1987-1997)

J. Michael Rowe
Consultant
Former Director, NIST Center for Neutron Research (retired 2004)

Richard E. Toohey
Director, Dose Reconstruction Programs, Oak Ridge Associated Universities

The statement of work for the experts asked them each to:

- Identify the cause(s) of the incident and any contributing factors;
- Evaluate the NIST response to the incident;
- Evaluate the report on the incident that will be prepared by the NIST Ionizing Radiation Safety Committee at the request of the NIST Deputy Director; and
- Provide the NIST Deputy Director with their individual recommendations on the following: (a) corrective actions, (b) avoiding future incidents, and (c) improving safety performance and incident response.

The five external experts conducted their on-site review in Boulder from June 23-24. These experts wrote individual reports with their preliminary findings and submitted them to NIST Deputy Director James Turner between June 27 and July 9.

III. Relevant Background Information

A. Description of NIST Boulder laboratories

Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Department of Commerce. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. The agency operates in two primary locations: Gaithersburg, Maryland, (headquarters—234-hectare/578-acre campus) and Boulder, Colorado, (84-hectare/208-acre campus). The Boulder facility was constructed in the early 1950s and commissioned by President Dwight D. Eisenhower in 1954. Originally motivated by the need to accommodate expanding radio and cryogenic research, today the NIST Boulder Laboratories have more than 350 scientific, technical, and support staff, and more than 300 visiting researchers, students, and contractors. Research in Boulder includes major programs from many of the NIST laboratories, including the Physics Laboratory, Chemical Science and Technology Laboratory, Electronics and Electrical Engineering Laboratory, and the Materials Science and Engineering Laboratory. Key areas include: standards for time and frequency; quantum electrical standards; nanotechnology; atomic, molecular, and optical physics; electromagnetics; and optoelectronics.

Activities conducted at the NIST Boulder Laboratories are organized within the same organizational framework as those in Gaithersburg. The Director of the NIST Boulder Laboratories does not have direct line management authority over programs in Boulder. Line management authority rests with corresponding Operating Unit (i.e. Laboratory) management for each of the activity areas. In fact, the current Boulder Director is also a full-time Division Chief of the Physics Laboratory's Time and Frequency Division. The primary functions of the Boulder Director are to provide for the supervision of central support functions in Boulder and act as a central spokesperson and coordinator.

The Quantum Sensors Project team in Boulder was most directly involved with the plutonium contamination event. This is an approximately 20-person project team led by a Project Leader. The specific research program most involved in the incident is led by the Principal Investigator (PI). The Quantum Sensors Project team is part of the Quantum Electrical Metrology Division. The Division is part of the Electronics and Electrical Engineering Laboratory.

These relationships are summarized in the organizational chart shown in Figure 1.

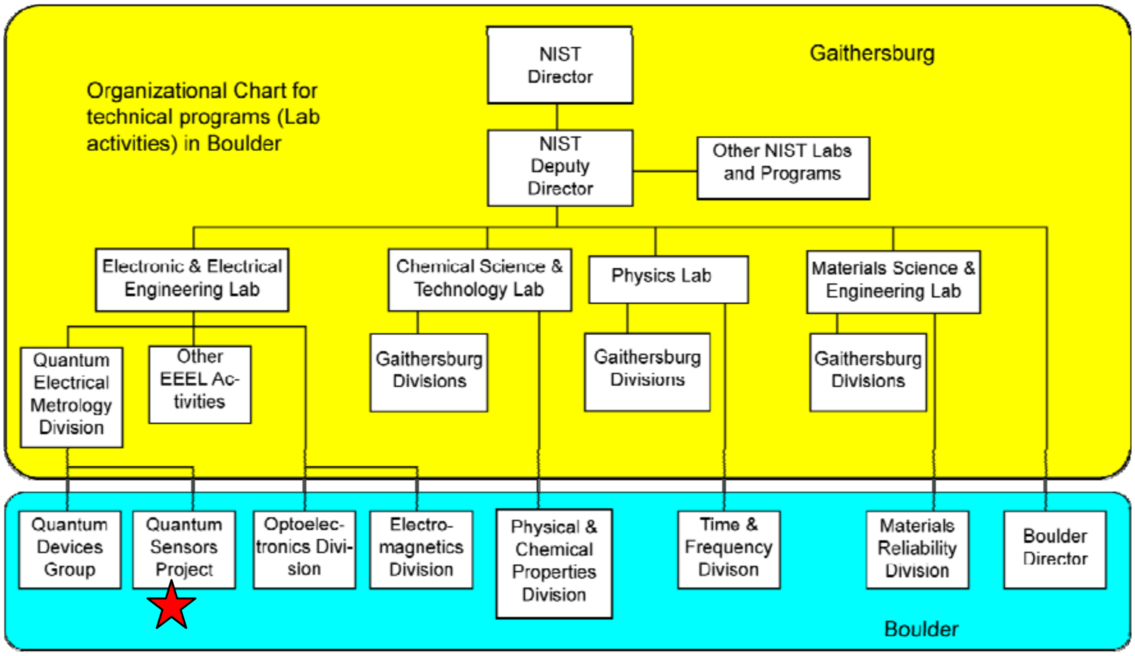

Figure 1. Organizational chart for research activities in Boulder. The organization directly involved in the incident is marked with a (★).

Similarly, the NIST safety office functions are organized across Gaithersburg and Boulder. The Director of the NIST Safety, Health and Environment Division (SHED) reports to the NIST Chief Human Capital Officer, who reports to the NIST Deputy Director. The Director of SHED supervises both the head of the Boulder Office of Safety, Health, and Environment, which includes the Boulder Radiation Safety Officer (RSO), and the Leader of the (Gaithersburg) Health Physics Group. There is no direct reporting relationship between the Boulder RSO and the Gaithersburg-based Health Physics Group. These relationships are summarized in the organizational chart shown in Figure 2.

Figure 3 shows the physical layout of the laboratory 2124 where the spill occurred.

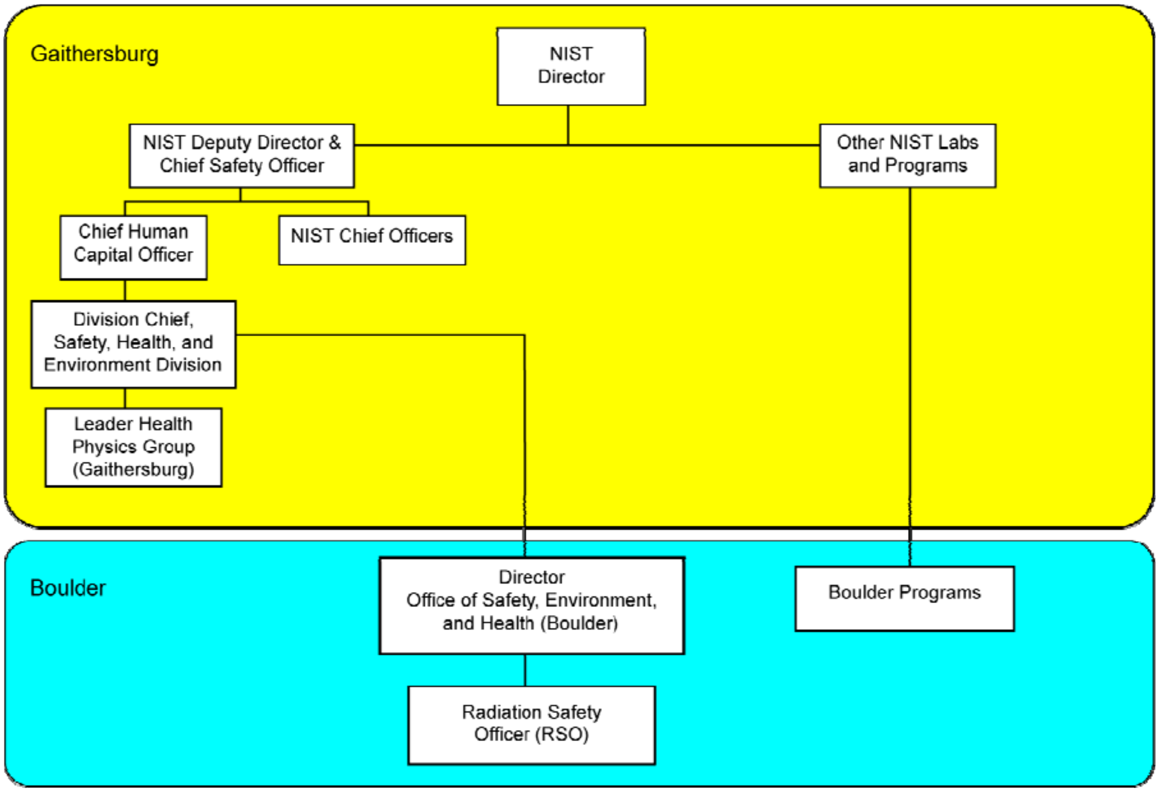

Figure 2. Organizational chart illustrating how the NIST safety office functions are organized across Gaithersburg and Boulder.

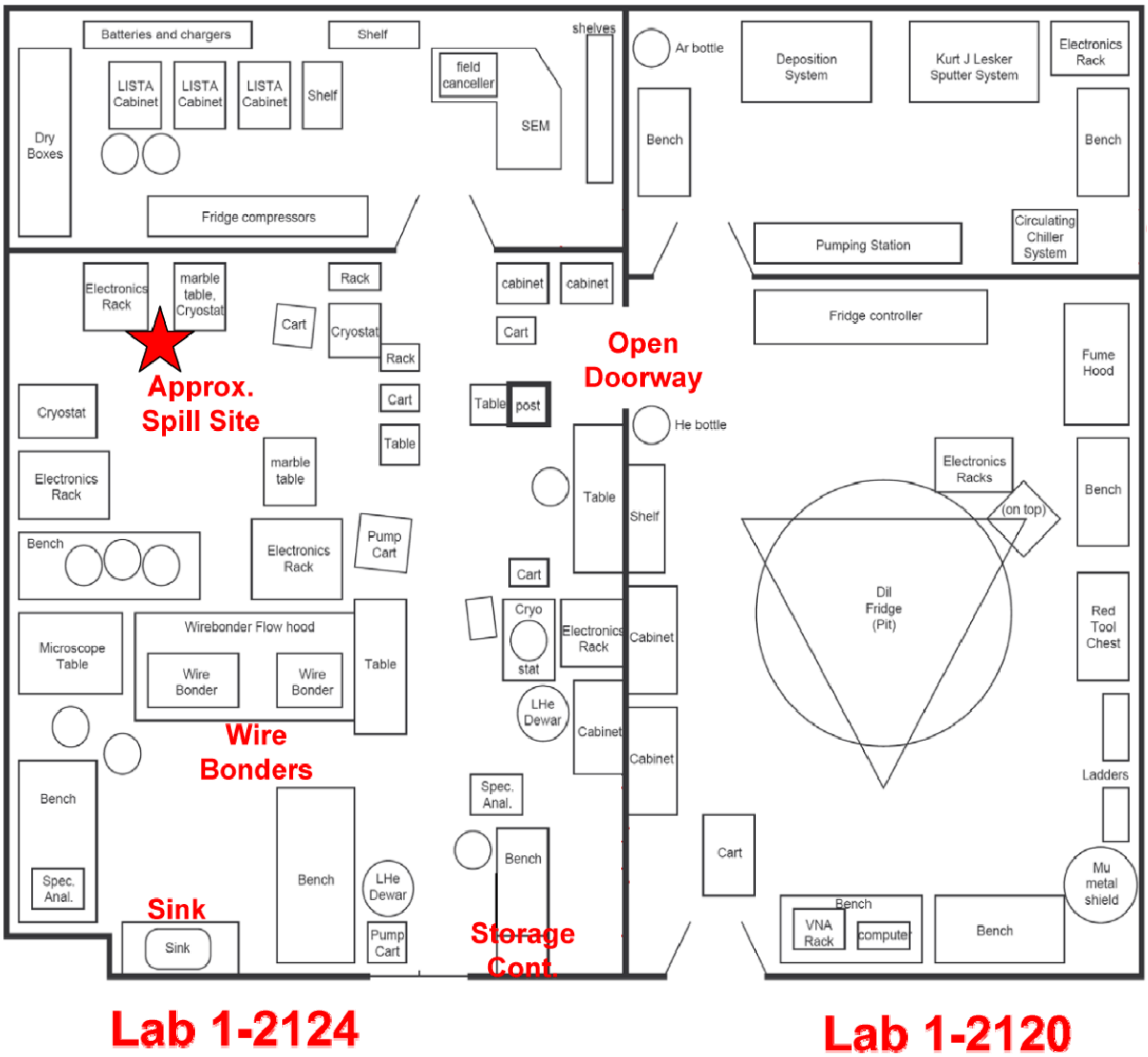

Figure 3. Plan view of the lab where the spill occurred and the connected labs that were isolated due to the incident.

B. Research Program Description

The Quantum Sensors Project develops detectors optimized for several ranges of the electromagnetic spectrum, as well as particles. Almost all these detectors are based on cryogenic microcalorimeter sensor circuits and SQUID readout circuits made at NIST. The combination of these technologies allows for the creation of sensor arrays with improved energy or power sensitivity compared to other technologies. For example, NIST sensor and/or SQUID components are used worldwide in a large number of astronomical instruments that measure millimeter-wave and submillimeter-wave emissions.

Work on sensors for nuclear materials analysis began approximately three years ago and is performed in close cooperation with Los Alamos National Laboratory. The work had two components: microcalorimeters optimized for gamma ray detection used to analyze larger samples, and microcalorimeters optimized for alpha particle detection used to analyze trace samples. The goal of this work was to provide improved detection technology for nuclear safeguards and forensics. For gamma rays near 100-keV, microcalorimeters provide approximately 10 times better energy resolution than competing germanium sensors. This spectral clarity allows improved measurements of plutonium isotopics for nuclear materials accounting and enables the discrimination of uranium from a radium background. For alpha particles, microcalorimeters provide approximately eight times better energy resolution than competing silicon sensors. This spectral clarity allows improved isotopic and mixed actinide measurements. These improvements, in turn, can reduce the time for certain nuclear forensic analyses from weeks to days. Both gamma ray and alpha particle sensors are tested using radioisotopic sources, and spectra from plutonium are particularly valuable because they are one of the motivating applications for the sensor development.

The program to develop detectors for nuclear materials analysis had succeeded in taking microcalorimeter technology from proofs-of-principle to early measurement systems. For instance, a NIST-designed gamma-ray microcalorimeter system is installed at Los Alamos (Figure 4), and a series of improving upgrades are planned. The program receives significant outside agency support from the Department of Energy, and the scope of the program has grown as the viability of the technology has become clearer. The program has produced a large number of publications and presentations as well as a recent description in *Scientific American* (November 2006). The work is also included in the 2007 addendum to the PAssive Non-Destructive Assay (PANDA) manual, which is the classic reference on non-destructive nuclear material measurement and accountability.

The experiment underway at the time of the accident was the acquisition of a high statistics plutonium gamma ray spectrum with a newly installed array of microcalorimeter detectors (Figure 5). Previous microcalorimeter spectra had shown higher spectral resolution than a high-purity germanium measurement but had less statistical significance because of the smaller detector area and number of counts. The increased size of the new detector array was intended to improve the statistical significance of the microcalorimeter results to a level similar to germanium. On June 7, the first high statistics spectrum was acquired. On the day of the accident, June 9, a second acquisition was planned at a lower count rate in order to improve the energy resolution.

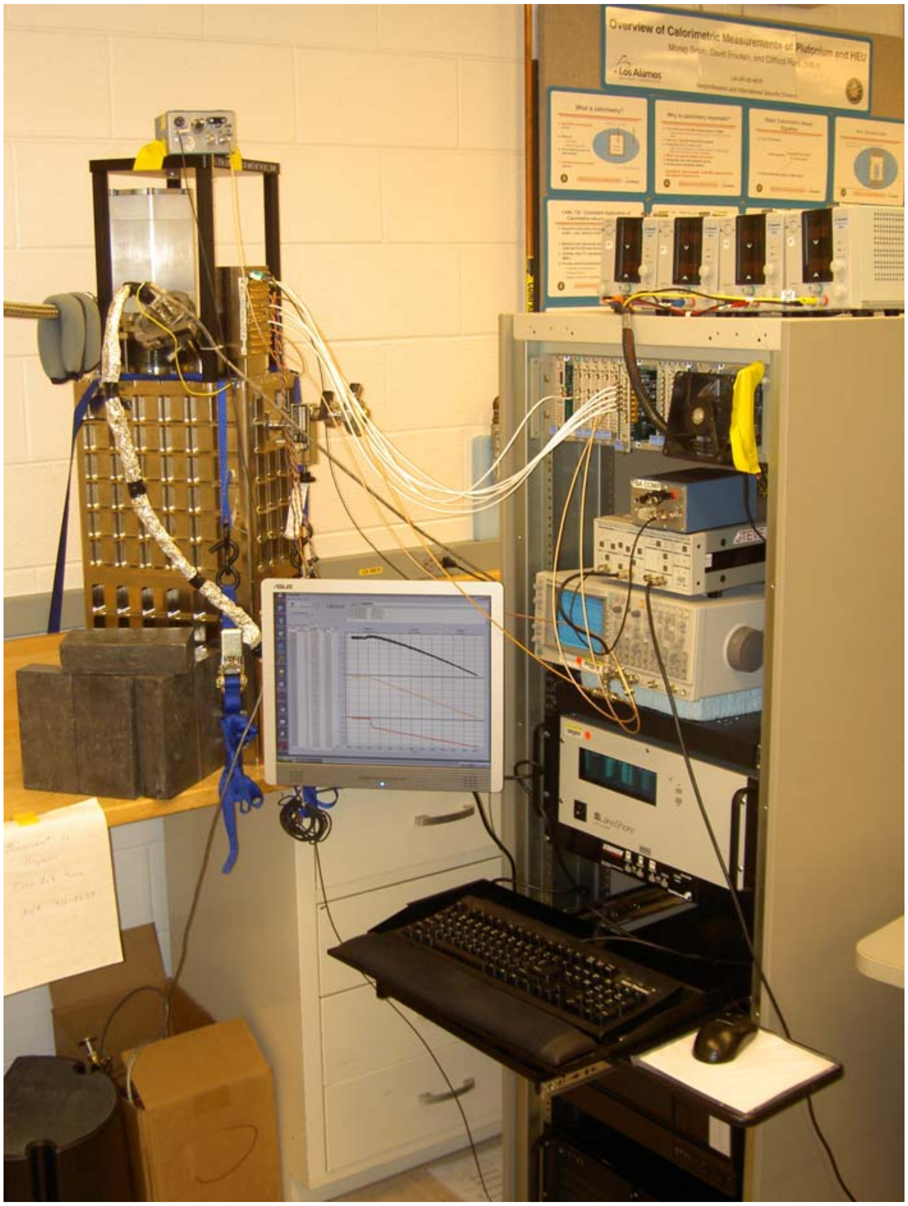

Figure 4. Photograph of NIST-designed microcalorimeter gamma-ray spectrometer. The pictured spectrometer is located at Los Alamos National Laboratory. This is NOT the instrument where the accident of June 9 occurred. However, the appearance of the two units is similar. The detectors are located in the aluminum vacuum vessel shown at left. The approximate height of the vacuum vessel is 1 meter.

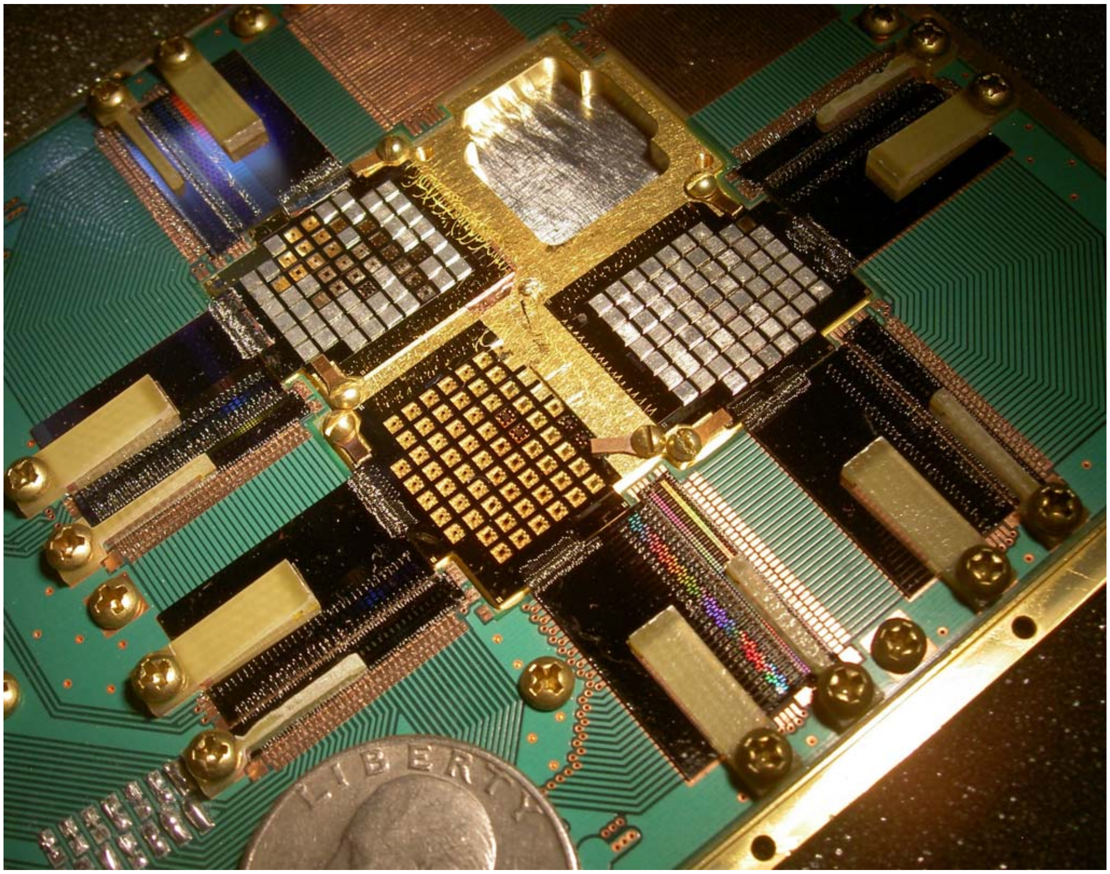

Figure 5. Photograph of gamma-ray microcalorimeter arrays and SQUID readout circuitry. Silver-grey squares are individual sensing elements and are 1.5 mm on a side. The accident of June 9 occurred during testing of the sub-array on the right side of the figure.

C. Description of plutonium source

Plutonium is a radioactive element with an atomic number of 94. It was discovered in 1941, and although it exists in very trace amounts naturally, it must be considered for all practical purposes to be an artificial element. Plutonium is produced in reactors from the absorption of neutrons by uranium. Plutonium has 15 different isotopes, all of which are radioactive. Most of the radioactivity from plutonium isotopes is from the emission of alpha particles (helium nuclei), though a fraction of the radioactivity also results in the emission of beta and gamma radiation, as well as from spontaneous neutron emission. Shown in Figure 6 is a table that lists the radioactive decay properties of the major plutonium isotopes and important plutonium decay products:

DOE-STD-1128-98

Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities

Table 2.3. Radioactive Decay Properties of Selected Isotopes and Decay Products, Excluding Spontaneous Fission[a]

Isotope	Half-Life	Mode of Decay Particle	Energy, MeV	Yield,d%	X-ray[b] Energy, MeV	Yield, %	Gamma Ray Energy, MeV	Yield, %
^{236}Pu	2.851 y	α	5.77	69.3	L's 0.011-0.021	13[c]	0.0476	6.6×10^{-2}
		α	5.72	30.6			0.109	1.2×10^{-2}
^{238}Pu	87.7 y	α	5.50	71.0	L's 0.011-0.021	10.5[c]	0.0425	3.95×10^{-2}
		α	5.46	28.8			0.0999	7.35×10^{-3}
^{239}Pu	2.41×10^{4} y	α	5.157	73.1	L's 0.0116-	5.0[c]	0.099	1.22×10^{-3}
		α	5.144	15.0	0.0215		0.129	6.41×10^{-3}
		α	5.106	11.8			0.375	1.55×10^{-3}
							0.414	1.46×10^{-3}
^{240}Pu	6564 y	α	5.168	72.8	L's 0.0115-	10.8[c]	0.0452	4.50×10^{-2}
		α	5.124	27.1	0.0215		0.104	7.08×10^{-3}
^{241}Pu	14.35 y	β	0.0052[d]	100.00	—	—	0.077	2.20×10^{-5}
		α	4.896	2.04×10^{-3}			0.1037	1.01×10^{-4}
							0.114	6.0×10^{-6}
							0.149	1.9×10^{-4}
							0.160	6.71×10^{-5}
^{242}Pu	3.73×10^{5} y	α	4.901	77.5	L's 0.0116-	9.1[c]	0.0449	3.6×10^{-2}
		α	4.857	22.4	0.0215		0.104	7.8×10^{-3}
^{241}Am	432.2 y	α	5.486	85.2	L's 0.0119-	42[c]	0.0263	2.4
		α	5.443	12.8	0.0222		0.0332	1.2×10^{-1}
		α	5.388	1.4			0.0595	35.7
^{237}U	6.75 d	β	0.039[e]	0.8	L's 0.0119-	70[c]	0.0263	2.43
		β	0.050[e]	3.4	0.0206		0.0595	34.5
		β	0.065[e]	51		53	0.0648	1.28
		β	0.069[e]	42	K's 0.097-0.114		0.165	1.85
							0.208	21.1
							0.268	7.1×10^{-1}
							0.332	1.2
							0.335	9.5×10^{-2}
							0.369	4.0×10^{-2}
							0.371	1.1×10^{-1}

(a) Data from Dunford and Burrows (1993).
(b) L's = L X-rays; K's = K X-rays.
(c) Total for all X-rays. The value represents an average obtained from data at Pacific Northwest Laboratory, Lawrence Berkeley Laboratory, and Lawrence Livermore Laboratory.
(d) Average beta energy given. The maximum beta average for ^{241}Pu is 0.0208 MeV.
(e) Average beta energy. The maximum beta energy for ^{237}U is 0.248 MeV.

Figure 6. Table 2.3 taken from DOE-STD-1128-98 "Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities", which shows the decay properties of the major plutonium isotopes and important decay products.

Occupational hazards from plutonium are predominantly from the radioactivity of the material (the chemical toxicity is much smaller). The dominant form of radiation from plutonium is alpha radiation, which is easily stopped by relatively thin shielding materials (even including the intact, external surface of skin). Therefore plutonium does not produce a great deal of highly penetrating radiation, and the external exposure risk is from the emission of X-ray and low energy gamma rays from plutonium isotopes and plutonium decay products. The dominant radiological hazard from plutonium is from *internal* contamination by inhalation, ingestion, or injection. The much greater risk results from the tissue damage caused by the alpha particles from the radioactive decay of plutonium that, once inside the body, are in direct contact with local tissue. Plutonium is best considered as a potent radiotoxin. The specific health effects from plutonium uptake depend on the method of exposure (i.e. from ingestion, inhalation, or injection), the chemical form of the plutonium, and on the distribution and retention of the plutonium in the body. This will not be considered further in this initial report but is an essential consideration for assessing internal dose and estimating its potential effects.

The researchers in Boulder purchased three plutonium isotopic sources for their work in October 2007; two sources of Certified Reference Material (CRM) 138 and one source of CRM 137. The source involved in the contamination was a CRM 138 source. The sources were purchased from the Department of Energy's New Brunswick Laboratory (NBL). CRM 138 is an isotopic standard, originally issued in the late 1960s by the National Bureau of Standards as Standard Reference Material (SRM) 948. Because of the relatively short half-lives of some of the plutonium isotopes, its isotopic composition has changed considerably since it was originally issued, and daughter isotopes have grown in. The material is reported to have an initial purification date of July 6, 1962. Its initial and current isotopic compositions are given in Table 1.

Isotope	Initial	Current
^{238}Pu	0.0099	0.010
^{239}Pu	91.298	91.949
^{240}Pu	7.896	7.925
^{241}Pu	0.763	0.083
^{242}Pu	0.033	0.033

Table 1. Calculated initial (July 6, 1962) and current (July 1, 2008) isotopic compositions of CRM 138 in atom percentage based on a Certificate of Analysis dated October 1, 1987.

The large reduction in ^{241}Pu content over 46 years has been replaced by its radioactive decay products ^{241}Am (0.632 atom percent of the Pu) and ^{237}Np, the decay product of ^{241}Am (0.048 atom percent of the Pu). The specific activity of the current composition is 6.8×10^9 Bq/g (0.185 Ci/g) consisting of 53 % alpha activity and 47 % beta activity.

Each CRM source consists of approximately 0.25 grams of plutonium in the form of $Pu(SO_4)_2 \cdot 4H_2O$ (plutonium sulfate tetrahydrate), which is a stable, coral pink salt (crystalline powder), and moderately soluble in water. The primary packaging for the plutonium sulfate tetrahydrate compound consists of a screw-cap glass bottle with a Teflon gasket. The bottle is made of clear glass and is approximately 2 cm in diameter and 4 cm tall, including the cap. It is believed that the glass bottles used by NBL were the same used at the time of manufacture of the compound in the 1960s. The bottle volume of approximately 12 mL is much larger than the volume of the plutonium compound. Assuming the density of the plutonium sulfate tetrahydrate is 10 g/mL (similar to that of most plutonium compounds) then the volume of the source is only about 0.05 mL.

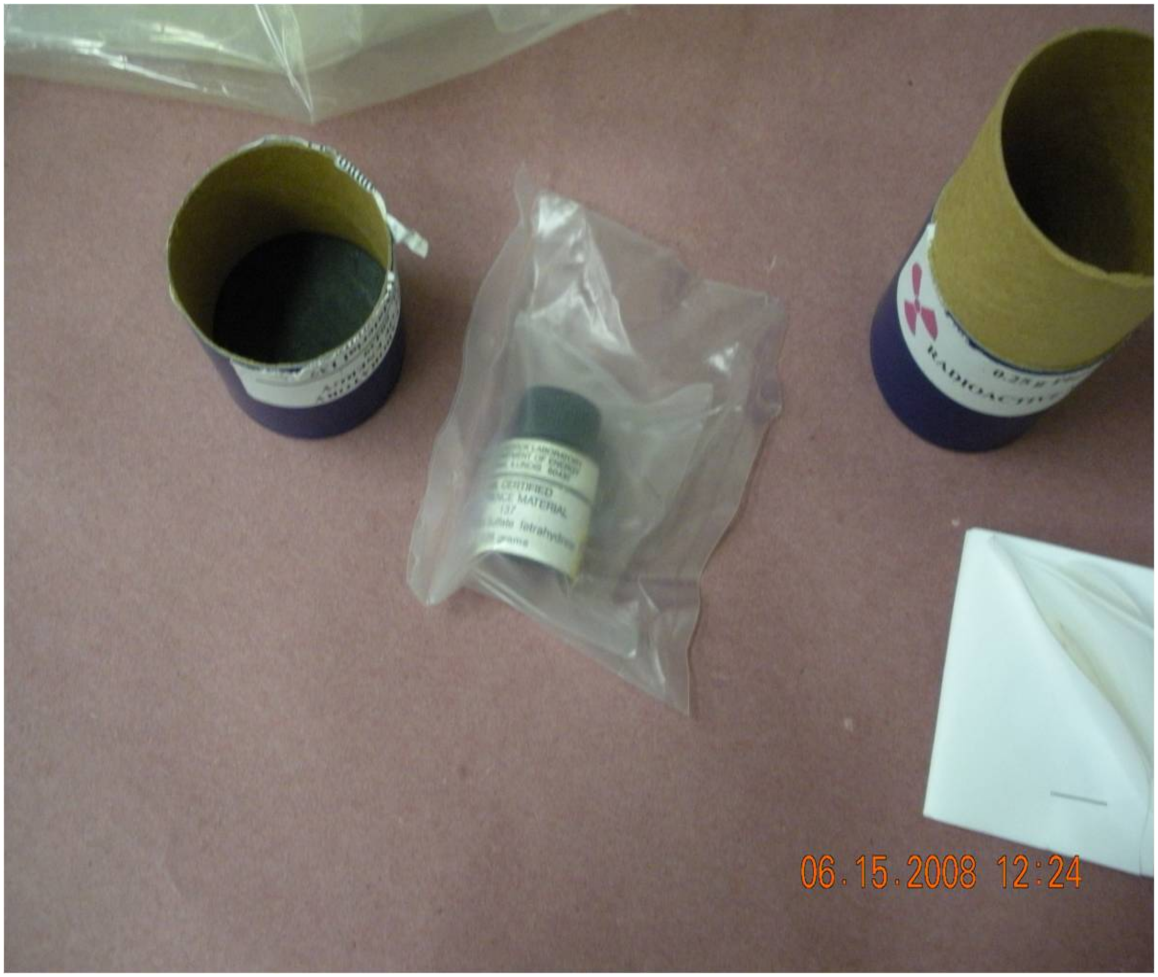

Figure 7. Photograph from the DOE RAP team investigation of one of the undamaged sources (CRM 137) still in the original sealed plastic bag.

Secondary packaging is also provided for the CRM sources. Based on discussions with NBL personnel (and confirmed by testimony from NIST personnel), the additional packaging consisted of placing the glass source bottle in a single or double heat-sealed polyethylene bag that was placed into a labeled cardboard tube. This method of packaging is shown in Figure 7, which shows a photograph of an undamaged CRM 137 glass-bottled source. The cardboard tube was then placed into a metal can and closed with a canning machine. Both the cardboard tube and the metal can were labeled. For shipment, additional packaging was used. The three glass-bottled sources located in their cans were loaded together into a flanged and bolted steel container (i.e. “pipe nipple”), which was then placed with other packing material into a 55-gallon sized DOT type B shipping container. The shipment also contained a material safety data sheet (MSDS).

D. Description of NIST Boulder Materials License

The activities involving the use of radioactive materials in Boulder are covered under a license issued by the Nuclear Regulatory Commission (NRC). The NRC issues specific radioactive materials licenses for the specific use of prescribed materials for a specific function or project by specified individuals or groups. The requirements and conditions for such a license are determined based on the form and amounts of materials listed in the application for the license. All requirements are stipulated and implemented by the actual license document and are typically very prescriptive. There are specific regulatory criteria that must be met to satisfy the requirements of this specific category of radioactive materials license. The NIST Boulder radioactive materials license is a NRC approved specific radioactive materials license.

This is distinct from the situation in Gaithersburg. The NRC also issues broad scope radioactive materials licenses, which offer a high degree of latitude in the acquisition and use of materials as well as the disposition of the materials as specified in the terms of the license. The program at NIST Gaithersburg is under a broad scope license. Under this type of license, general requirements are implemented through programs and policies set by the licensee, such as the administration of a radiation safety program and administrative oversight policies. A broad scope license allows the licensee to propose their own methods to manage radiation related issues as determined by a Radiation Safety Committee (RSC) and/or facility management. The licensee must demonstrate a high level of competence, expertise, and control in the handling and use of radioactive materials in order to qualify for this category of license.

As the program activities in Boulder changed, they required amendments to be approved by the NRC in order to specifically allow the new activities. Relevant to this review, the license in Boulder was modified six times during the period between 2003 and 2007. These modifications are listed in Table 2.

Amendment	Purpose	Requested	Approved
24	Change of Radiation Safety Officer (Ringen)	7/31/2003	9/3/2003
25	Request for additional isotopes	10/20/2004	12/8/2004
26	License renewal (timely submission)	12/15/2004	5/11/2005
27	Request for additional isotopes Change of Radiation Safety Officer (Grimm)	10/19/2006	1/18/2007
28	Request for additional isotopes (including limited quantity SNM)	2/15/2007	4/19/2007
29	Request for additional isotopes	6/13/2007	6/22/2007

Table 2. Amendments made to modify the Boulder NRC License number 05-03166-05 during the period 2003 to 2007.

E. NIST Policies dealing with the use of radioactive materials

The NIST Safety Operational System (SOS) is defined in the NIST Administrative Manual in Chapter 12.01. The system is based on strong line management responsibility for all aspects of safety performance, including responsibility for safe conduct of operations, for developing achievable safety performance goals, and for procedures that foster a culture of safety — defining and expecting accountability for results and minimizing hazards in the work place. The NIST SOS covers all activities at NIST, including those dealing with radiological hazards. The policy defines specific roles and responsibilities within the organization.

NIST policy specifically covering the use of radioactive materials is summarized in the NIST Administrative Manual, Chapter 12.03. The specific sections pertaining to the NIST Boulder activities are (as presently posted):

12.03 RADIATION SAFETY (excerpted)

<u>Sections</u>

12.03.01. PURPOSE: The purpose of this subchapter is to outline responsibilities and prescribe procedures for radiation safety at NIST and to incorporate by reference certain procedures and instructions pertaining to radiation safety.

12.03.02. SCOPE: The provisions of this subchapter apply to all NIST employees at Gaithersburg and Boulder who may be occupationally exposed to radiation sources and to non-NIST employees whose assignments at NIST involve operations, equipment, or facilities that may result in radiation exposure.

12.03.03. DEFINITIONS:
a. <u>Radiation</u> - For the purpose of this subchapter, radiation includes (1) ionizing radiations, such as x-rays, emissions from radioactive materials, or beams from the reactor or accelerators; and (2) non-ionizing radiations from laser beams and microwave sources.
b. <u>As Low As Reasonably Achievable (ALARA)</u> - The lowest achievable levels of radiation exposure and release of radioactive material when taking into account the state of technology, the economics of precautions in relation to benefits, and the beneficial utilization of atomic and nuclear energy.

12.03.04. POLICY
a. It is Institute policy to maintain radiation exposure and release of radioactive materials in unrestricted areas to magnitudes as low as reasonably achievable (ALARA).

b. Operating procedures at NIST must ensure that exposure to ionizing radiation be kept ALARA but in any event within the limits established in applicable regulations.

12.03.05. RADIATION SAFETY PROGRAM
At NIST-Boulder procedures pertaining to radiation safety must be reviewed and approved in writing by the Mountain Administrative Support Center (MASC) Radiation Safety Officer or as required by specific licenses.

12.03.06 RADIATION SAFETY COMMITTEES

The Laser Safety Committee at Boulder is described in Boulder Administrative Bulletin 84-2.

12.03.07 RESPONSIBILITIES

NIST, as a licensee of the U.S. Nuclear Regulatory Commission (NRC) has the following responsibilities:

NIST-Boulder:

a. The Director, NIST-Boulder Laboratories, is responsible for:
    1. Establishing an effective radiation safety program at Boulder;
    2. Handling matters which involve the position of the Boulder laboratories as a licensee of the NRC; and
    3. Reporting to the NRC on defects and items of noncompliance with NRC regulations relating to Boulder laboratory operations.
b. The MASC Radiation Safety Officer at the Boulder Laboratories is responsible for:
    1. Ensuring compliance with NRC licensing requirements;
    2. Establishing procedures required to obtain NRC approval for new uses of radiation sources and maintaining records of all sources;
    3. Establishing rules and procedures required to promote radiation safety; and
    4. Providing training and retraining in radiation safety for employees.
c. Division Chiefs at Gaithersburg and Boulder are responsible for:
    1. Ensuring that staff members comply with radiation safety rules in implementing the NIST radiation safety policy;
    2. Ensuring that staff members are aware of radiation safety procedures and receive training as required;
    3. Reporting potential items of substantial radiation hazard to the Leader, Health Physics Group (at Boulder, MASC Radiation Safety Officer), within 24 hours of occurrence or discovery, except for items relating to the reactor license which are to be handled according to that license; and
    4. Reporting significant radiation safety matters to their supervisors.
d. NIST employees and other individuals working on the NIST site are responsible for:
    1. Observing approved radiation safety rules;
    2. Consulting with the Health Physics Group (refers to the Gaithersburg Health Physics Group or the MASC Radiation Safety Officer at Boulder) early in the planning of operations that might involve radiation sources;
    3. Obtaining authorization from the Health Physics Group for radiation source acquisitions, for any modifications in radiation source use that might affect radiation safety, or for disposition of radiation sources;
    4. Notifying the Health Physics Group of any occupational radiation exposure from work at facilities other than NIST;
    5. Immediately informing the Health Physics Group upon discovery of loss or theft of any radioactive materials;
    6. Immediately informing their supervisor and the Health Physics Group of accidents involving radiation or radiation sources; and
    7. Informing their supervisor of defects that could create a substantial safety hazard.

These procedures are out of date. In 2003, RSO responsibilities in Boulder were transferred from MASC to NIST Boulder. Also, in 2006 NIST Director William Jeffrey announced changes in the responsibilities for the Boulder Director. These changes included realigning safety responsibilities from the Boulder Director to the NIST Safety, Health, and Environment Division (email from W. Jeffrey to all staff, September 29, 2006). These changes are not reflected in the published policy and clearly impact the responsibilities defined in Section 12.03.05.

IV. Summary Description of Event

(Detailed summary is included in Appendix A.)

Summary:
On the afternoon on June 9, 2008, a sample of plutonium sulfate tetrahydrate in a glass bottle while being used by an untrained Worker 1 was mishandled and broke during an experiment. The resulting spill of the plutonium compound contaminated the area near the experiment. Subsequent actions by Worker 1 and the PI spread the contamination within the lab, onto their persons, and outside the lab.

Major sequence of events:

The following major sequence of events was identified during the review:

(1) The NIST Boulder specific license with the NRC was amended to allow limited quantities of SNM, including solid, encapsulated plutonium (any isotope except Pu-238).

(2) Three plutonium sources were acquired without adequate hazard analysis or management approval. The wrong conclusions were reached regarding the hazards posed by the sources.

(3) Sources were received; all protective barriers were removed except the screw-topped glass bottle in a sealed plastic bag, inadequate and inappropriate controls are established, controls are informally communicated to the PI, and no specific training was provided to the PI.

(4) Inexperienced and untrained researchers began work on the detector project using radioactive sources.

(5) Researchers developed an inappropriate work plan, which involved removal of glass-bottled sources from their secondary barriers, directly manipulating the glass-bottled source with ungloved hands, and taping the bottled source to a fixed device in order to achieve a desired instrument response.

(6) The glass bottle was broken, spilling the plutonium compound.

(7) Worker 1 handled the source and significantly spread contamination in the work area and on his body (shoes and hands), causing potential intake of radioactive material.

(8) Worker 1 left the area and spread contamination outside of the affected laboratory.

(9) Worker 1 reported to the PI, stating that the "sample [glass-bottled source] may be cracked" and left for his office, leaving the PI to investigate the report alone.

(10) The PI reopened the closed metal container containing the broken glass source container, handled it in order to assess situation, and then repackaged it. These actions potentially dispersed more material into the area and increased the contamination of the laboratory and the risk of intake of radioactive material.

(11) The PI recognized the serious nature of the spill and the potential for contamination, ordered the evacuation of the lab, assembled the potentially affected personnel, reported the incident to the Safety Office and management, and began contamination control and assessment.

(12) The B-RSO arrived and began the organized response.

V. Analysis

Event-Causal Factors Analysis
The IRSC review is charged with identifying the cause(s) of the incident and to identify contributing factors. This type of analysis is at the heart of any review that seeks to identify appropriate corrective actions designed to prevent recurrence of similar events. The IRSC review used the DOE Root Cause Analysis Document (DOE-NE-STD-1004-92) as a reference for performing this analysis. Based on this document, we present below a summary of events and a causal factor analysis. For this type of analysis the following definitions are used:

> **Event**: a real-time occurrence
>
> **Condition:** Any as-found state, whether or not resulting from an event, that can have an adverse impact on the outcome.
>
> **Cause (causal factor):** An event or condition that affects the outcome.
>
> **Causal factor chain:** a cause and effect sequence of causal factors.
>
> **Direct cause:** a cause that directly resulted in the occurrence.
>
> **Contributing cause:** a cause that contributed to, but by itself did not, cause the occurrence.
>
> **Root cause:** a cause that, if corrected, would prevent recurrence of this and similar occurrences.

As a preliminary analysis of this incident, the IRSC employed a basic event-causal factor analysis consisting of constructing a basic causal factor chain and identifying their associated contributing causes (in bullet form below). For the purposes of this review, the IRSC summarized major causal events in the timeline beginning with the approval of the license change in Boulder to the beginning of the organized response at 18:00 on June 9. From that point on, we believe that the incident was fully developed and the stage set for most of the consequences that followed.

In the Recommendations, the IRSC addresses the need for a more complete and formal Root Cause Analysis.

(1) The NIST Boulder specific license with the NRC was amended to allow limited quantities of SNM, including solid, encapsulated plutonium (any isotope except Pu-238).

Contributing causes:

- The NIST Boulder program in the EEEL Quantum Sensor Project was growing and requesting new sources of different isotopic composition than generally used in Boulder;

- The growth of the program in Boulder resulted in increased scrutiny by NIST Health Physics and the IRSC. This attention resulted in a series of audits and reviews and culminated in the decision to strengthen the program by hiring someone with health physics expertise into the Boulder safety program.
- In October 2006, NIST Boulder hired a Health Physicist and modified the NIST Boulder license to make him the B-RSO;
- Shortly after arrival, the B-RSO began to work with the detector project PI to draft an amendment to the license allowing limited quantities of Special Nuclear Material (SNM), including plutonium;
- The suitability of the specific license in Boulder for limited quantities of SNM was discussed between the B-RSO, NIST HP (Gaithersburg), and the NRC. It was decided that the specific license process was appropriate;
- In January 2007, the draft license amendment was extensively discussed by the IRSC.
- No discussion was made of specific sources (the license language is general);
- The IRSC did not require any specific controls on the Boulder program if the license was approved;
- The IRSC assumed that the B-RSO would raise any specific concerns to the IRSC if a new source with substantially different properties was proposed.

(2) Three plutonium sources were acquired without adequate hazard analysis or management approval. The wrong conclusions were reached regarding the hazards posed by the sources.

Contributing causes:

- Programmatic considerations (i.e. desire for specific isotopic composition) led the PI to chose CRMs 137 and 138 from NBL for the research project;
- Programmatic and project considerations initially led the PI to consideration of larger sources (Type B) and different chemical forms (plutonium oxide). However, shipping restrictions from NBL limited acquisition of the larger sources, which contributed to the decision to procure the smaller Type A sources;
- The B-RSO was actively involved in the selection and procurement of sources from NBL, but did not raise any concerns except for the acceptability under the approved license;
- Safety considerations arising from this type of source material were not part of the early market research;

- NBL raised concerns about acceptability of sources under the NIST license, but the NRC independently confirmed to both NIST and NBL that CRM 137 and 138 sources were allowable;
- NBL discussed appropriate handling precautions with the PI by both phone and email. These communications suggested that NIST told NBL that sources would only be used while remaining inside their cardboard tubes;
- In the same discussions NBL instructs the PI that any materials inside the cardboard tube would have to be treated as possibly contaminated with plutonium powder;
- The B-RSO raised concerns to the PI that the PI was untrained for dealing with unsealed sources and suggested (but did not implement) gluing the lid of the glass-bottled source in place to make opening the source bottle more difficult;
- No notification was made by the B-RSO or the PI to the IRSC regarding the planned procurement of powdered solid plutonium sources;
- A NIST 364, Request to Acquire a Radioactive Source, which is designed to ensure that a formal hazard review and management approval is completed before acquiring a new source, is not prepared prior to acquisition. (It is prepared later when the sources arrive);

(3) Sources were received; all protective barriers were removed except the screw-topped glass bottle in a sealed plastic bag, inadequate and inappropriate controls were established, controls were informally communicated to the PI, and no specific training was provided to the PI.

Contributing causes:

- Adequate hazard analysis or review was not performed in advance;
- The PI was inexperienced with this type of radioactive material;
- The PI did not receive any appropriate training regarding the safe use and storage of the plutonium sources or on the hazards associated with dispersible radioactive material;
- The PI and the B-RSO did not apply the appropriate controls, including those recommended by the supplier to leave the sources inside their cardboard tube;
- The sources were visually identified as “powdered” plutonium material in glass bottles, but this confirmation did not cause a re-evaluation of the hazard assessment or of the controls being applied;
- The NIST 364 was not correctly prepared before ordering the shipment and was filled out on the same day that the shipment was received;

- EEEL management did not seem to be involved or aware of the arrival of the sources and did not formally approve their acquisition on the NIST 364.

(4) Inexperienced and untrained researchers began work on the detector project using radioactive sources.

Contributing causes:

- The new researchers had no significant previous experience with radioactive materials;
- The new researchers were unfamiliar with NIST policies covering the use of radioactive materials;
- The new researchers were given general instructions on the detector system but no specific instructions on handling the radioactive sources;
- Worker 1 was given access to the radioactive sources in the locked storage cabinet by the PI;
- Worker 1 and Worker 2 received no formal radiation safety training;
- The PI did not require Worker 1 or Worker 2 to take radiation safety training before working with radioactive source materials;
- Other laboratory personnel reminded Worker 1 and Worker 2 to take radiation safety training, but the recommendation was not acted on;
- Worker 1 and Worker 2 did not attend any general safety orientations provided by NIST;
- There is a history of low participation and attendance at the general safety orientations provided in NIST Boulder;
- Worker 1 and Worker 2 were not issued personal dosimeters by the B-RSO;
- Worker 1 and Worker 2 recognized that they had not been issued personal dosimeters (and that others had) but took no corrective actions;
- The facilities to conduct the experiments were inadequate for this type of activity. They were crowded and poorly laid out;
- The work area was not restricted or controlled for radiological work. It resided in a busy, multi-use laboratory;
- Hazard posting on the laboratory was minimal and mostly unrecognized by the laboratory users;
- The work procedures involved leaving the source unattended and unsecured on the outside of the detector during experiments;

- The B-RSO was aware that new researchers were joining the detector project and needed training but took no follow up action;
- The B-RSO did not observe work in the lab with the sources;
- The B-RSO did not assess the knowledge or understanding of the researchers, the adequacy of their work controls and procedures, or their familiarity with policy or procedures (including reporting incidents);
- The role and function of the B-RSO was unknown to the participating researchers (until after the spill). They believed him to be a contractor who administered the personnel dosimeters.

(5) Researchers developed an inappropriate work plan (involving removal of glass-bottled sources from their secondary barriers, directly manipulating the glass-bottled source with ungloved hands, and taping the bottled source to a fixed device in order to achieve a desired instrument response).

Contributing causes:

- The workers were untrained in the appropriate use of the plutonium sources;
- The workers were unaware of the specific hazards associated with the source;
- The workers were not instructed by the PI regarding the handling of the source or the appropriate experimental steps;
- Specific hazard information, handling instructions, or control procedures were not communicated to or known by the workers;
- The workers were unaware of the physical form of the plutonium source (powdered solid) before removing the source bottle from the cardboard tube and examining it;
- The workers did not appreciate the significance of the hazard after discovering that the source was a radioactive powdered material.
- The original bag was significantly damaged from mishandling;
- It was not documented, understood, or appreciated that the cardboard tube and multiple bags were important secondary barriers for the glass-bottled source;
- The source had already been removed from its outer cardboard container and was routinely used without it;
- The informal experimental planning process included minimal consideration of safety;
- Worker 1 and Worker 2 were new and relatively inexperienced with the experimental setup and the source;

- Worker 1 felt time pressure to complete work (data were needed for an upcoming conference);
- Worker 3 with the most radiological training and experience was acting as an “expert consultant” and was not a regular participant in the experiment;
- Based on his actions, Worker 3 did not appear to have sufficient knowledge or experience to qualify him to handle this material or to act as an expert;
- Worker 3 reports feeling generally concerned about the containment of the plutonium in a glass bottle but did not act on these concerns;
- The workers did not recognize the substantial nature of the change in experimental procedures or its risk consequences;
- The workers did not discuss, assess, or review the consequences of the change in experimental procedures;
- The workers did not notify the B-RSO or the PI regarding the change to experimental procedures, source controls, removal of barriers, or direct manipulation of the source. There was no expectation that such notification should occur;
- The PI was unaware of the changes in work procedures and source handling;
- The PI was not typically involved in the operations using the source.

(6) The glass bottle was broken, spilling the plutonium compound.

Contributing causes:

- Worker 1 is believed to have been working alone at the time of the spill;
- The work area near the detector was congested;
- Lead bricks were added to the area near the detector to protect a computer;
- The location of the computer screen showing detector performance was not in the line-of-sight from the source position/detector area;
- Worker 1 was using a blind operation involving manual manipulation of the source to optimize the count rate;
- Appropriate handling instructions or controls were not provided;
- Worker 1 was untrained and inexperienced using this class of material or source;
- Worker 1 was untrained and inexperienced with general radiological safety protocols;
- No appropriate procedures had been established for this activity;

- Inappropriate actions similar to those presumably taken by Worker 1 had been planned on the Friday before the spill;
- The PI was unaware of the changes in source handling and control made by Worker 1 and other researchers;
- The glass bottle containing the source may have been weakened from its age and long exposure to the radiation from the source (over 30 years);
- The glass-bottled source may have been previously mishandled, including tapping on a marble surface, which could have structurally weakened the glass.

(7) Worker 1 handled the source and significantly spread contamination in the work area and on his body (shoes and hands), causing potential intake of radioactive material.

Contributing causes:

- Worker 1 did not have any training or experience to prepare him to deal with an unsealed source or with how to respond to a potential contamination event;
- Worker 1 did not understand or appreciate the hazardous nature of the spilled material;
- Worker 1 did not understand or appreciate the potential for further dispersing the spilled material by handling it;
- Worker 1 did not use appropriate protective equipment or procedures to minimize the risk of exposure or dispersal of material;
- Worker 1 did not survey the work area with appropriate instrumentation to assess the situation (the instrumentation was available in the lab);
- Worker 1 did not use any appropriate personal protective equipment (PPE), such as gloves, to handle the broken glass source bottle.
- Worker 1 may have understood the potential for dispersing the material and took actions (e.g. taping closed the opening of the metal can) to prevent spreading contamination;
- No procedures or instructions were available to or known by Worker 1 for dealing with a broken or spilled source;
- Hazard and control information from the source manufacturer, including instructions on what to do in the event of a spill, was not communicated, available, or known to Worker 1.

(8) Worker 1 left the area and spread contamination outside of the affected laboratory.

Contributing causes:

- Worker 1 did not seem to understand or recognize the potential to spread contamination;
- Worker 1 was untrained and had no experience related to dealing with a contamination event;
- Worker 1 did not act with any apparent sense of urgency (e.g. stops to talk to other researchers on the way out) indicating that he may not have recognized the hazardous conditions in the contaminated laboratory and the need for immediate corrective action;
- Worker 1 reported the incident to his supervisor personally and did not use other communication methods that would have allowed him to stay in place (e.g. phone or a message passed by another worker);
- No other affected workers in the lab were told of the hazardous conditions and continued to enter and work in the contaminated lab.

(9) Worker 1 reported to the PI, stating that the "sample [glass-bottled source] may be cracked" and left for his office, leaving the PI to investigate the report alone.

Contributing causes:

- Worker 1 did not seem to understand the severity of the contaminated conditions in the lab;
- Worker 1 had no training or experience in reporting a potential radiological event;
- Worker 1 did not adequately describe the nature of the incident, the current status in the laboratory, or the actions he had taken;
- Worker 1's report did not appear to convey any sense of urgency to the PI;
- The PI did not seem to question Worker 1 regarding the incident or lab conditions, possibly assuming that the situation was not immediately hazardous;
- Worker 1 and the PI did not immediately report to other persons (e.g. Boulder Safety Office, HP, or management) as would be appropriate for a potential radiological event.

(10) The PI reopened the closed metal container containing the broken glass source container, handled it in order to assess situation, and then repackaged it. These actions potentially dispersed more material into the area and increased the contamination of the laboratory and the risk of intake of radioactive material.

Contributing causes:

- The PI had incomplete knowledge of the situation probably due to poor communication with Worker 1;
- The PI was untrained and inexperienced in dealing with spreadable contamination;
- The PI did not consider the potential hazards associated with the investigation of a potentially broken source containing a radioactive powder;
- Procedures had not been established to deal with a broken source bottle;
- The PI did not apparently realize the risk of airborne contamination and did not establish appropriate controls;
- The PI did not try to survey work areas with available instrumentation to assess the situation and determine the potential for contamination before handling the source;
- The PI did not appear to have immediately recognized the need to establish access control to the laboratory;
- The PI did not seek qualified assistance from HP before examining source.

(11) The PI recognized the serious nature of the spill and the potential for contamination, ordered the evacuation of the lab, assembled the potentially affected personnel, reported the incident to the Safety Office and management; and began contamination control and assessment.

(12) The B-RSO arrived and began the organized response.

VI. Findings:

The causal factors identified in this analysis can be characterized into categories of cause types. Examples include (from DOE Root Cause Analysis Document DOE-NE-STD-1004-92): equipment/materials, procedural problems, personnel errors, design problems, training deficiencies, management, and external phenomena. This categorization allows for a more detailed exploration of a “nexus” of problems and facilitates identification of the underlying root cause(s). In this preliminary report, the IRSC does not perform a formal characterization analysis of each causal factor. However, we did informally discuss and review the types of causal factors identified in our analysis and explored patterns in these causes. We also note that the associated reports from SHED/OSHE, EEEL, and the external subject matter experts all provide some type of analysis of the nature of these causal factors. Our major findings are summarized below.

Root cause:

Based on our preliminary analysis, we believe that the most probable root cause of the incident is a failure in the existing NIST safety management system as it was applied to the detector project being carried out by the researchers in Boulder. The failure was exacerbated by a casual and informal research environment that appears to have valued research results above safety considerations. This failure was evidenced by widespread deficiencies noted in the sequence of events that can be traced directly to the roles and responsibilities that were neither clearly defined nor clearly understood by Boulder personnel and are at the heart of both the NIST Radiation Safety Program and the NIST SOS, including:

- Ensuring that appropriate radiation safety requirements and processes are established;
- Ensuring that researchers and line management are aware of radiation safety requirements and processes;
- Ensuring that researchers comply with radiation safety requirements and processes;
- Ensuring that researchers and supervisors have adequate training to perform their assigned work — and conversely not assigning work to persons untrained and unqualified to perform that work;
- Ensuring that researchers and first-level supervisors adequately understand the hazards in their workplace and take appropriate action to control them;
- Applying effective assessment and review processes to identify hazards and establish appropriate controls;

- Providing adequate resources and facilities to ensure the safe conduct of operations;
- Appropriately supervising work; and
- Monitoring and auditing activities and programs for safety effectiveness.

Direct causes:

- The most probable direct cause of the spill event is striking the glass bottle containing powdered plutonium sulfate tetrahydrate, which had been removed from all other secondary protection and containment, against a fixed obstacle during the experiment;
- The most probable direct cause of the larger scale of the contamination event (beyond that arising only from the spilled source powder on the workbench) is the direct handling of the broken source bottle by (likely) both the researcher and his supervisor on at least two separate occasions without adequate controls;
- The most probable direct cause of the spread of contamination outside the laboratory area is the multiple, uncontrolled entries into and exits from the contaminated laboratory after the spill;
- The most probable direct cause of the release of plutonium into the sanitary sewer was Worker 1 washing his hands in the sink after they were contaminated and a failure to retain the water to prevent it from entering the drain. (Worker 1 did not report washing his hands until June 16.)

Discussion of key contributing causes:

- The failure to properly recognize the significant hazards associated with a powdered plutonium source contained only by a glass bottle had devastating consequences for the subsequent events. This determination should have been made at the time the source was being procured through an appropriate hazard analysis involving the PI, B-RSO and EEEL line management. (However, there were other missed opportunities later in the process.) The failure to properly assess the hazards and risks resulted in the following types of deficiencies in downstream events: inadequate and improper controls, improper training, inadequate notification, inadequate review, inadequate and improper procedures, inadequate and improper response, inadequate preparation for an accident, inadequate protective equipment, etc;
- The participants failed to understand that this work represented a significant risk change from the previous radioactive source work in Boulder. Although concerns

and specific hazard information regarding this source were raised on many separate occasions, this information and these concerns never resulted in appropriate corrective actions;

- The incident was characterized by widespread failures to apply established procedures, controls, methods, and training requirements needed to safely work with this class of radioactive material. In some cases, participants seemed unaware of required or appropriate procedures or controls. In other cases, they seemed to know them but failed to apply them correctly. In some instances, they recognized a requirement (e.g. for basic radiation safety training) but failed to take appropriate action;

- The IRSC approved changes to the Boulder license that was non-specific for limited quantities of SNM (under Amendment 28) but failed to ensure suitable controls so that any specific source acquired would not exceed the capabilities of the radiation protection program in Boulder.

- Many contributing events were characterized by a cavalier attitude regarding the safety consequences of work with this type of material, combined with a strong focus on getting research results;

- Key participants, including the B-RSO and the PI, did not appear to have understood their roles, responsibilities, authorities, or accountability under the NIST radiation safety program or NRC license covering activities in Boulder. This deficiency played a significant role in their failures to adequately review hazards, design and apply appropriate controls, properly authorize workers to use radioactive material, provide adequate supervision, and ensure that workers were qualified to conduct the work through adequate training; and

- The sequence of events covered by this review is notable for the complete absence of any role by the EEEL program line managers. NIST policy gives them a direct and critical role as defined above under the root cause description. However, in our review of the incident, we found almost no evidence of any involvement by any level of EEEL management from the time the source is acquired until the early stages of the initial response to the spill.

VII. Recommendations

The IRSC recommendations are based on the preceding analysis and findings. The recommendations are organized as actions to be taken to address problems or weaknesses identified or suggested by this review. The IRSC recommends that:

A. Immediate corrective actions:

1. **NIST stop all research with radioactive materials in Boulder until a specific and complete work plan is prepared, reviewed, and approved.** Specifically,

    - Any plan must address: authorized use; hazard assessment; include copies of proposed worker training and qualifications materials; provide a description of the laboratory and supporting facilities; access controls; source controls; barriers, and administrative controls; personnel dosimetry; work surveillance; work procedures; and plans for dealing with off-normal events.

    - These plans should be prepared and submitted by the line organizations including and up through at least the Division Chief level of the Division proposing the work. The plans should be reviewed by the Gaithersburg HP Group and the IRSC.

    - If approved and if necessary, an appropriate license change should be prepared with strict limitations consistent with the approved program. The IRSC will review the amendment request in the context of the approved plan.

2. **NIST should take immediate corrective actions to ensure that existing radiation safety policy and procedures are being effectively applied within the EEEL programs in Boulder.** NIST management should use its authority to ensure that roles and responsibilities to carry out the established safety program are clearly defined and implemented and to ensure that supervisors and staff are held accountable for effectively meeting these requirements. A necessary step is to ensure that the appropriate personnel have the knowledge, skills, and judgment to meet their roles, responsibilities, authority, and accountability within the program and under the license.

3. **NIST should take immediate corrective actions to ensure that the existing radiation safety policies and procedures are being effectively applied within the programs managed by OSHE.** The role of the RSO in an effective radiation safety program is essential. NIST management should use its authority to ensure that the roles and responsibilities of the B-RSO and other associated OSHE personnel are being effectively carried out to provide effective oversight for the activities in Boulder. A necessary step is to ensure that the appropriate personnel have the knowledge, skills, and judgment to meet their roles, responsibilities, authority, and accountability within the program and under the license.

4. **The IRSC recommends that the ongoing planning to stabilize, decontaminate, and recover the laboratory by qualified experts be done as quickly as practicable, making sure that all activities are appropriately planned and meet any regulatory requirements.** There are small but increasing risks with leaving the lab in a contaminated condition.

B. Actions to improve safety performance at the NIST Boulder Laboratory:

NIST should re-evaluate the organizational lines of responsibility and accountability as they exist between Gaithersburg and Boulder in order to strengthen safety performance and make any changes deemed appropriate. The lines of responsibility and accountability need to be sufficiently strong to ensure effective program management, safety management, and incident response to emergency and off-normal conditions.

C. Actions to improve overall NIST safety performance:

1. **NIST should supplement the recommended corrective actions by performing independent assessments of safety management performance at NIST.**

    - Given the likely nature of the root cause of this event, these independent assessments must have a large external component;
    - The assessments need to be critical and penetrating if they are to provide actionable information;
    - They should also be sustained at a frequency that allows progress toward implementing required changes to be monitored;
    - Adopting a risk-based methodology is a sensible approach to prioritize assessments in different activity areas.

2. **NIST should strengthen its safety culture by securing the commitment and active participation of senior NIST management and by developing and executing a well-defined plan to effectively integrate safety management practices into core NIST management functions.**

    - The full integration of safety practices into routine management functions is at the heart of promoting and sustaining a "safety culture" (similar to the integration of program direction, budget, personnel, and other core management performance areas);

- Management attitudes that safety management practices are "add-ons" that impede creative research must not be tolerated. An effective and sustainable safety culture requires strong commitment and active participation from the entire organization, starting at the very top;

- The most effective safety practices are those that are an essential part of doing everyday work — not special, extra activities that are done on an occasional basis. It is essential to implement a routine set of practices that ensures that high quality research is done in a way that minimizes the risk to the safety and health of the researchers at NIST;

- This change will involve integrating safety policy and practice into all core management functions, including: decision making, priority setting, business systems, organizational performance review, and personnel performance management;

- This change will require a strong and sustained commitment on the part of NIST management to be implemented effectively.

3. **NIST should take steps to expand and strengthen its Safety Office immediately**.

   - The safety management responsibilities of workers and line management are best met with the full partnership of a proactive and empowered Safety Office staffed with professional safety experts;

   - The NIST Safety Office is presently understaffed to meet the needs of a technical research organization the size of NIST, and NIST management is consequently underserved;

   - A strengthened NIST Safety Office will be able to provide the expertise to develop an effective general safety training program and to support the effective implementation of that program;

   - The roles, responsibilities, and authority of Safety Office personnel need to be clarified to foster an effective and empowered office that can proactively promote safety and a strong safety culture within the agency.

D. Actions to improve the effectiveness of the NIST IRSC and Radiation Safety Program:

1. **The IRSC will strengthen its oversight over the radiation safety programs at NIST (Gaithersburg and Boulder) by creating a standing Safety Audit Committee with external radiation safety experts to regularly audit and review the programs using radioactive materials at NIST.**

2. **The IRSC will reassess its Charter and procedures and recommend changes in order to ensure that new radioactive sources or changed uses of radioactive sources that fall outside the umbrella of previously reviewed uses and procedures are properly reviewed by the Committee before they are authorized to be acquired or used in the requested manner.**

3. **The IRSC will request the SHED to reassess staffing and equipment needed to support an effective radiation safety program at both the Boulder and Gaithersburg campuses. The IRSC will review and recommend accepted changes to the NIST Deputy Director.**

E. Actions to complete review of this incident:

This preliminary report under this phased review should be supplemented with additional elements in order to provide a complete assessment of the incident and the NIST response. In order to meet our charge, we recommend that the NIST Deputy Director approve additional review activities (and associated resources if they are to be performed by contract), for the following areas:

- Formal Root Cause Analysis (contract);
- Incident management and communication: Lessons Learned review (external); and
- Health Physics response, including dose assessment and decontamination (external).

F. Actions to ensure full implementation:

Finally, the IRSC recommends that all of these recommendations (and any others that result from additional analysis) be incorporated into a Corrective Action Implementation Plan with identified action "owners" and specific dates for completing proposed actions. The Plan should include a process to assess and document the effectiveness of those actions and should be revised accordingly and in a timely manner.

The Corrective Implementation Action Plan should be actively managed and tracked using available management systems and regularly reviewed by NIST management.

Appendix A. Detail Chronological Description of Event

Given the complex set of events that preceded this event, the IRSC review has summarized the investigative findings into the following chronological summary. For clarity, the chronology is broken up into distinct phases with a summary of major findings at the end of each phase. References to the appropriate source material from the investigation are listed as deemed appropriate. The summary covers events from the IRSC review of the Boulder program starting in 2005 and follows up to the beginning of the organized response to the event at 18:00 on June 9, 2008. From that point on, we believe that the incident was fully developed and the stage set for most of the consequences that followed.

A. Early IRSC involvement and Boulder license modifications

Date	**Event**
7/31/03	NIST requests a change in the Boulder license to make Sonja Ringen RSO.
9/3/03	NRC approves the 7/31/03 request as Amendment 24.
10/20/04	NIST requests a change in the Boulder NRC license to add additional isotopes.
12/8/04	NRC approves the 10/20/04 request as Amendment 25.
12/15/04	NIST requests a license renewal for activities in Boulder (timely submission).
Late 2004	Boulder indicates that they would like to change from a Specific License to a Type B Broad Scope License; the HP-GL begins to explore this possibility.
3/16/2005	Boulder relicensing is discussed at the IRSC meeting; concern is expressed by the Chair and an IRSC review was made an Action Item.
April 26-27, 2005	IRSC subcommittee conducts on-site review of Boulder radiation safety program. The review finds significant weakness in the documentation and implementation of requirements of the NRC license.
5/2/05	IRSC Chair forwards interim report with the findings from Boulder review to the Acting NIST Deputy Director, Rich Kayser. In response, Dr. Kayser asks the IRSC to prepare a report of the review findings with recommended corrective actions.

5/6/05	IRSC subcommittee discusses the Boulder relicensing effort and the results of the IRSC subcommittee review.
5/11/05	NRC approves the 12/15/04 license renewal request as Amendment 26. IRSC transmits its final and summary reports of the Boulder review to Rich Kayser.
5/16/05	NIST HP group transmits its recommended implementation of the plan for implementing corrective actions to Rich Kayser.
5/22/05	Rich Kayser requests a detailed action plan to implement the recommendations of IRSC report and the HP implementation plan.
6/7/05	The HP-GL presents the IRSC with options for a future Boulder license; discussion was tabled for two weeks to gather more information.
6/23/05	IRSC resolves that Boulder safety office needed a full-time HP for the RSO and tighter IRSC oversight.
6/28/05	IRSC transmits to Rich Kayser its final recommendations regarding the Boulder radiation safety program. These recommendations include: • Hiring a new safety staff member in Boulder with the knowledge, skills, and experience to support the licensed activities in Boulder; • Maintain a specific type materials license in Boulder.
6/30/05	Rich Kayser stops acting as NIST Deputy Director. In a transition memo to NIST Deputy Director, Hratch Semerjian, Dr. Kayser requests that he follow up on all of the IRSC recommendations.
July 2005	NIST Acting Director Semerjian is reported to have agreed to hire “another person” for the Boulder safety office.
July 2005 – April 2006	Boulder receives approval to hire a health physicist. The OSHE Director reports a long conversation with an NRC inspector indicating that no inspection of the Boulder radiation safety program is necessary at this time.
July 2006	HP safety audit performed at Boulder indicates improvement over previous audit.
10/2/06	The new HP begins work in Boulder.

10/19/06	NIST requests change in Boulder NRC license to add additional isotopes and to make the new HP the B-RSO.
Late 2006	The B-RSO requests an amendment to the current Boulder NRC license and drafts a license application to add additional SNM isotopes to the Boulder NRC license in response to expanding work being done by EEEL.
1/17/07	IRSC reviews proposed request to amend the Boulder NRC license. At the IRSC meeting, there is much discussion on the Boulder plans to expand the scope of RAM usage by the EEEL. The need for a better description of the meaning of “spent fuel” was also discussed. The IRSC raises concerns that the utilization of the SNM sources remain consistent with the type of sources traditionally used in the Boulder programs and that higher level radioactivity work must be performed at the LANL. There is no discussion of any particular source at the meeting. IRSC agrees to the proposed license amendment.
1/18/07	NRC approves the 10/19/06 request as Amendment 27.
2/15/07	Request for license amendment is submitted by the B-RSO to the NRC.
4/19/07	NRC approves the 2/15/07 Boulder license change request as amendment number 28.
6/13/07	NIST requests a license change to add new isotopes.
6/22/07	NRC approves the 6/13/07 request as Amendment 29.

Additional findings:

- From late 2004, the IRSC is aware of the growing detector program in Boulder and the increased interest in obtaining more sources. A primary concern at this time is managing the increasing number of license amendments that would be required. There is some discussion about moving the Boulder program to a limited broad scope type license.

- The IRSC sent the Gaithersburg RSO, a Certified Health Physicist (CHP), and an EEEL program representative to audit the Boulder radiation safety program in April 2005. While in Boulder, they provided basic radiation safety training to all the individuals identified as potentially working with radioactive material. This training satisfied the basic requirements of 10CFR19 and specifically addressed safe handling of the sources present in the inventory and approved in the Boulder NRC license at that time.

- A key finding of the IRSC audit is that the Boulder program should remain under a specific license and that further consideration of a broad scope license would depend on a stronger radiation safety program, including new staff, and the ability to demonstrate sustained improvement in the performance of the radiation protection program.

- A Health Physicist was hired as on October 2, 2006, in response to IRSC recommendations to support license activities, as well as to perform other health and safety responsibilities. Equipment and funding support for the position was limited due to a delayed implementation of the reorganization of the Boulder Safety Office under SHED. Equipment needs were initially satisfied primarily by the loan of instruments from the Gaithersburg HP Program. Eventually (late 2007-early 2008), the RSO was able to purchase equipment to support the operations listed under the Boulder NRC license.

- Boulder license amendments are not generally reviewed by the IRSC. The discussion on January 17, 2007, is the first license amendment request for the Boulder license discussed and reviewed by the IRSC.

B. Acquisition of plutonium sources

Date	**Event**
4/28/07	Email from the B-RSO to the PI: “I received the amendment to our NRC license to possess Uranium, U-235 (limited enrichment) and Thorium. ... We have some work to do before you order sources. First thing will be training, so let’s get together and set up some times. ... I’ll be helping you set up your lab for the safe handling of the sources, and I need the expected dose rates / activities / nuclide information.” Email from the PI to the B-RSO: “Does the amendment also cover Pu isotopes?”
4/30/07	Email from the B-RSO to the PI: “Yes, we are authorized for ‘Any plutonium isotope except Pu-238; Any solid, encapsulated form; 15 grams total, not to exceed 4 grams per source.’”
7/7/07	Email from the PI to the B-RSO: “To purchase type B Pu sources (~ 1 gram) we need a special waiver on national security grounds. I think it would be no problem to prepare the request for such a waiver. We can presently purchase type A sources (~ 0.25 gram) without additional paperwork. I’m happy to prepare the request but wanted to get your opinion on whether this was a good idea or not.” Certificates for CRMs 122, 126-A, 128, 130, and 138 attached.

8/8/07	Email from the B-RSO to the PI: "I see no problem ordering the CRM-122 (Type B) quantity other than: 1) we need to do the justification, and 2) it may take a while for NBL to get the exemption."
8/20/07	Email from a NBL representative to the PI: "As we discussed, NBL is not authorized to ship Type B quantities at this time, however, if you have a national security need we may be able to seek an exemption from our moratorium on these shipments. CRMs 122 and 126-A are Type B quantities. CRM 126-A is stored offsite, so we may be able to ship this material without seeking an exemption. Plutonium CRMs 128, 130 and 138 are Type A quantities of Pu, so we can ship these CRMs, no problem." Email from the PI to a NBL representative: Request for availability and cost of CRMs 136 and 137 Email from the PI to a NBL representative: DOE form 540a attached: Domestic Order Form for CRMs, signed by the PI Email from the PI to a NBL representative: Request to purchase Type B radioactive sources attached Email from the PI to the B-RSO: "Before I fill out sections 6-8, I'd like to be sure that you approve the source purchase." Email from the B-RSO to the PI: "The sources you are requesting are within our license limitations, therefore it is perfectly okay to purchase them." Email from the PI to the B-RSO: "Please send a copy of our NRC license to a NBL representative and NBL." Email the B-RSO to a NBL representative: "So you can send [the PI] some sources, attached is pdf of our NRC license." Memo from the PI to NIST Purchasing: Request for convenience check for $2,295 to purchase one unit of CRM 137 and two units of CRM 138
8/21/07	Email from a NBL representative to the PI: "I need to discuss your NRC license with [the B-RSO]. The license allows for any Pu isotope, except Pu-238, as 'any solid, encapsulated form'. I do not believe that our CRMs meet the definition of encapsulated. I will discuss this with [the B-RSO] and get back to you." Email from the B-RSO to the PI: "I spoke with … our NRC licensing guy. He indicated that the term 'encapsulated' is not defined by NRC. Therefore, because the material is a 'solid', which is the driving word in our license,

	and the material is in a screw top bottle, then he sees no problem with us receiving the material. ... As you and your staff are not trained to open source material (unsealed, free chemical, et cetera) I am a little nervous that you folks are receiving a bottle that can be opened. If it won't interfere with your experiments, we may wish to consider using some sort of sealant on the screw cap to make it difficult to open the bottle."
8/22/07:	Email from the PI to a NBL representative: "Just wanted to check if you had come to a consensus with [the B-RSO] and the NRC." Email from a NBL representative to the PI: The NRC "confirmed that screw-top glass vials [glass-bottled source] can be considered as 'encapsulated form', so we are okay on that front. … I will pursue the exception for a Type B shipment and will keep you posted."
8/27/07	Email from NBL Reference Materials Program Coordinator to the PI: "As we discussed, the CRM 137 and 138 materials are contained in small, screw-top glass bottles. They are inside plastic bags and then placed into cardboard mailer tubes or steel pipe stems. ... I'll make sure with our packaging folks that the two materials you're interested in are available in cardboard tubes. As I mentioned on the telephone, all users should consider everything inside the outer container (cardboard tube or pipe stem) to be contaminated with loose Pu. It is our recommendation to all of our customers that, if it is necessary to open the outer package, that operation should only be done in a glove box. Since it seems you have no need or plans to open the outer container and you can use the material in its original, unopened container, I don't think there will be any problems. Also, your suggestion to place the items into an additional container is a good one in my opinion, especially if you have good labeling for your users to understand not to open the container."
8/28/07	Email from the B-RSO to the PI: "It appears that you are on track for getting your Pu source and we are just awaiting Type B approval."
8/31/07	Email from the PI to a NBL representative: "Just wanted to check in and see if there was any news on our application for B sources."
9/13/07	Email from a NBL representative to the PI: "I still have not received a decision from the Laboratory Director regarding your order."
9/19/07	Email from the PI to a NBL representative: "Is there any additional news on our request? . . . If our request for B sources is not granted then yes we still want to purchase the two A sources." Email from the B-RSO to NRC: "Per our conversation, this is a request to obtain a RIS code for NRC License #05-03166-05."

	Email a NBL representative to the PI: “We received approval to ship your order and hope to have it ready the week of October 1st.”
9/28/07	NBL shipping form authorized
10/2/07	Email from the PI to the B-RSO: “Do you know anything about this RIS code that NBL needs? It seems to be what's holding up our Pu order.”
10/4/07	Email a NBL representative to the PI: “Your order was shipped this afternoon… It should arrive within one week.”
10/10/07	The B-RSO reports to the IRSC the NRC approval of the license amendments and indicated that he has received a RIS # for the NMMSS database, but that at this point he has no reportable quantities of SNM.

Additional Findings:

- The PI determines that the isotopic composition of Pu in CRM 137 and CRM 138 from New Brunswick Laboratories will satisfy the program needs.

- The B-RSO is aware of the PI’s interest in obtaining plutonium sources shortly after approval of the license change (April 2007) to allow plutonium isotopes and becomes heavily involved in helping the PI find sources.

- In the summer of 2007, the PI and the B-RSO are actively exploring the purchase of larger plutonium sources, including plutonium oxide. The larger, type B, sources have a mass approximately four times larger than the type A sources eventually purchased. The B-RSO approves the purchase and states that it is within license limits but notes that there are new security requirements to meet (but believes that NIST can meet them). Eventually NBL indicates that type B shipments are not authorized at this time, and the PI and the B-RSO discuss the purchase of the Type A sources. (*There is no apparent discussion of the hazards or risks posed by these larger sources and chemical forms of plutonium, in spite of the fact that they would have likely caused a much more serious contamination event if they had been broken in the same manner as the CRM 138 source.)*

- NBL representatives raise concerns about whether the powdered plutonium in a glass bottle can be considered an “encapsulated” source and therefore allowed under the NRC license for NIST Boulder. The NRC independently confirms to the NIST RSO and to the NBL officials that since “encapsulated” is undefined by the NRC, the operative word is “solid form” and that therefore the sources are allowed.

- NBL officials communicate specific hazard information to the PI including contamination controls and the importance of secondary packaging (namely the cardboard “mailing tube”). From the discussions it is apparent that NBL understands that NIST only intended to use the sources from within (i.e. without opening) the cardboard tubes and would label them with this restriction.

- The B-RSO raises specific concerns to the PI about the powdered form of the sources and the glass bottle encapsulation. He notes that the PI and his team are “not trained for open source work”. In response to this concern, he proposes but does not carry out an inappropriate control (to glue the screw top on the glass bottle) rather than address the training deficiency.

- Three sources were ordered from New Brunswick. Two were CRM 138, one was CRM 137.

- A NIST Form 364 (Request for Acquisition of a Radiation Source) was not completed prior to acquisition but was filled at when the sources were received. The sources are successfully ordered without this authorization.

- The sources are shipped and arrive at NIST Boulder on 10-11-07. The B-RSO reports to the IRSC meeting the day before that the Boulder program has no reportable quantities of SNM and makes no mention of the new sources.

- **The acquisition of the source is a pivotal moment in the unfolding of this event.** By failing to adequately identify the potential hazards associated with these sources — in spite of the fact that more than enough specific information was available to do so — a sequence of actions and decisions took place that had a direct impact on the accident with the source and the resulting contamination. These actions and decisions included: lack of training specific to the source, lack of appropriate controls, missing or inappropriate hazard communication, lack of experimental planning, lack of review and reporting, etc.

C. Receipt and storage of sources

Date	**Event**
10/11/07	Boulder receives three CRM Pu sources (0.25 g each) from NBL.
*10/11/07 or after 10/25/07	The shipment is unpacked. Statements indicate that the B-RSO unpacks the shipment and the PI is present. Other unidentified persons were present as well. NIST Form 364 (Request to Obtain Radioactive Source) is filled out and signed by the B-RSO and is dated 10/11/07. The glass-bottled sources arrive each packaged in one or two heat-sealed plastic bags inside a cardboard tube and inside a metal can. Individual sources are together inside a steel inner container, additional packing material, and a 55 gallon DOT Type B package.

	Memo from the B-RSO to the PI, stating that he would go over some Pu packaging issues with him and included in the message, "I'll go over some of this when we do the training next week". (However, the PI stated to the expert group that he had not received any special training related to his use of the Pu sources.) Statements from the PI indicate that he added an additional two plastic bags for each source some time between source receipt and first use of the source in April 2008. The original heat-sealed bags were observed to be intact at that time. The B-RSO states that the MSDS was removed from the package and reviewed with all of those present. ***The B-RSO states that containers were unpacked after training was completed. This would place the unpacking events detailed above sometime after 10/25/07. Statements from the PI indicate that he can not recall the time between receiving and unpacking the sources.**
10/12/07	Email from the B-RSO to a NBL representative: "The shipment was received safe and sound yesterday afternoon."
10/16/07:	Email from the PI to the B-RSO and the Project Leader: "I've ordered a fire resistant set of locking shelves for our radioactive sources." To arrive in two weeks. *Minor conflict with statements made by the PI that cabinets were likely in place at time sources were received but may not be a conflict if shipping container was opened after 10/25/07.
10/25/07	General Radiation Safety Training session conducted by the B-RSO for approximately 5-10 people. (No record of this training was provided to the IRSC.) None of the attendees interviewed remember any specific information provided about the nature, handling, or hazards of the Pu sources. Some participants mention that the training may have included general precautions on unsealed source use.
11/7/07:	The B-RSO reports to the IRSC that he is developing training presentations and programs for RAM use, laser use, and X-ray use

Additional Findings:

- The sources are received and unpacked at NIST either on 10-11-07 (as dated on the NIST 364) or received on 10-11-07 and unpacked sometime after 10-25-07 as stated by the B-RSO.

- The individual sources are unpacked through several layers of secondary packaging until reaching the glass source bottles enclosed in the original heat sealed bags: i.e. the outer cardboard tubes are opened. It is observed that the sources are powdered and that the heat sealed bags are intact.

- The glass-bottled sources are unpacked down to the plastic bags despite the recommendation from NBL to the PI to consider anything inside the cardboard tube as potentially contaminated and that opening the cardboard tube should be done in a glove box.

- A NIST 364 form is filled out by the B-RSO and dated 10-11-07. It appears to be filled out in its entirety by the B-RSO. No evidence exists to indicate that any management or their representatives sign or see the form (nor in testimony even seem to be aware of its existence). The review and approval process associated with the NIST 364 is not applied.

- The NIST 364 does not include specific written controls for handling the CRM 138 source;

- Statements suggest that the B-RSO instructed the PI to leave the sources in their bags. It does not appear that this information was documented.

- Statements suggest that the PI added additional plastic bags to the source at this time for additional protection. The PI states that the bags were added before the sources were ever used and that the original heat-sealed bags were observed to be intact at this time.

- The MSDS within the shipping package is retrieved by the B_RSO and given to the PI. Later, no one involved in the incident recalls being aware of information contained in the MSDS.

D. Training and early use of source up to June 9

Date	**Event**
12/06/07	Worker 1 joins NIST.
late 07	Dosimeters issued to six workers of group receiving Pu sources. (Does not include Worker 1 or Worker 2.)
3/08	New employee and associate safety orientation (offered quarterly) was not attended by Worker 1. Worker 1 later states that he was not aware of any new employee or associate orientation program.

3/08	Worker 1 and the PI begin to work together. Initial work consisted of noise measurements and does not include the use radioactive sources.
4/7/08	Worker 1 joins the spectrometry project.
Week of 5/5/08	Work begins with the plutonium sources. The PI reports adding two additional layers of ziplock bags to source at some time before this point. The PI reports not remembering whether he had a safety discussion with Worker 1 or Worker 2 before they began to use the source. No written procedures or protocols were developed for the experiments.
5/5/08	Worker 2 joins the spectrometry project.
late 4/08 – early 5/08	At least two discussions occur between the PI and the B-RSO regarding the need for training for two new researchers on the detector project. There is no follow up to these discussions.
5/08	An unnamed employee recommends to Worker 1 and Worker 2 on two separate occasions that they should get radiation safety training from the B-RSO. There is no reported follow up to this suggestion.
6/6/08 ~ 14:00	Worker 1 and Worker 3 work on optimization of the counting geometry for experiment in order to stabilize the count rate. (Worker 2 is reported to be present for much of this period, but his arrival/departure times are not known.) The glass-bottled source is removed from the plastic bags. It is inspected by hand and was determined to be a powder. Worker 1 and Worker 3 report that they were unaware of the form of the source material prior to the inspection. The glass-bottled source is reported to be intact at this time. Worker 3 and Worker 1 handle the glass-bottled source in an effort to achieve more reproducible count rates. Worker 3 reports gently tapping the glass-bottled source against a marble table in order to get the powder to settle into the bottom of the glass bottle. Worker 3 notes that the plastic bag containing the glass-bottled source is damaged (has holes in it). (No mention is made of the multiple plastic bags.) Worker 3 notes that prior to this point, the researchers were "stuffing" the

	glass-bottled source in its plastic bag into a pocket on the exterior shell of the cryostat (detector). Worker 3 recommends a more stable mounting arrangement and Worker 1 tapes the glass-bottled source to a square of copper, which is then held in place in a vice. Worker 1 recalls that the glass-bottled source was outside of the bags for this operation. Worker 3 expresses feeling vague but unstated concerns about the adequacy of the source packaging during these operations. (Worker 3 has past radiological training and experience.)
~ 16:00	Worker 3 leaves the lab.
~ 17:30	Worker 1 returns the glass-bottled source to the plastic bags. The bagged glass-bottled source was then placed in the metal can and stored in the fire safe storage cabinet.
6/7/08 ~ 9:00	Worker 1, while working alone in the lab, removes the glass-bottled source from storage, then places the glass-bottled source in front of detector with the glass-bottled source in the metal can, and begins to acquire data at 9:55.
6/8/08 ~ 19:00-19:30	Worker 1 stops data acquisition replaces the glass-bottled source back into the storage cabinet, then charges a battery and leaves for the day.

Additional Findings:

- New employee and associate general safety orientations are provided quarterly. These sessions were mandatory for employees and optional for associates. Records indicate that Worker 1 (an associate) was not registered and did not attend for a March 2008 session. Records also indicate that Worker 2 was registered for the March session, but he did not attend. The OSHE Manager indicated that there were only three attendees, despite a significantly higher number being registered. She indicated this is a typical response.

- There were several instances when it was suggested that Worker 1 and Worker 2 should receive radiation safety training. The PI reports that on two occasions he mentioned to the B-RSO that he had new researchers in need of training. Similarly, there was testimony that an unnamed coworker in the laboratory suggested to Worker 1 and Worker 2 that they should get radiation safety training. There was no follow up to these suggestions.

- Worker 1 was not issued personal radiation dosimetry by the B-RSO, and there is no evidence to indicate that dosimetry was requested. Worker 1 reports noticing that others had dosimeters and wondered why he did not. There was no follow up to this observation.

- Worker 1 remarks to the external experts that he was not aware of the B-RSO's role or title. He states that he thought he was a contractor that took care of the radiation badges (dosimeters).

- There is no evidence to suggest that the specific conditions for use of the sources under NIST policy or the license (e.g. intended use, training, etc.) were discussed with the participants, especially with Worker 1 or Worker 2.

- There was no evidence that Worker 1 or Worker 2 received any briefing or training on the safe use and handling of the sources, or that this topic was discussed. They do not recall any such training or instruction.

- The researchers were apparently not closely supervised by the PI when using the sources.

E. Events of June 9 between 13:00 - 18:00 (Spill and Contamination Event)

Time	Event
~ 13:00	Experiment setup began.
~ 13:15	Start of cooling and demagnetization of cryostat (detector).
~ 14:15	Cryostat (detector) is cold
~ 14:30	Worker 1 begins to make noise measurements with the detector and without source. (Duration unknown.) Worker 1 reports getting the key to RAM storage cabinet (it was stored in the desk drawer of a coworker for convenient shared use). Worker 1 recalls removing glass-bottled source from safe and placing it near the detector. The glass-bottled source is inside the metal can. (No mention of plastic bags in testimony.) Worker 1 recalls moving two lead bricks to the vicinity of the glass-bottled source in order to protect a nearby computer from "crashing" (he states the belief that the source was affecting the computer). Worker 1 recalls removing the glass-bottled source from the can and moving the glass-bottled source in front of the source in order to optimize the count rate (similar to the operation reported on 6/6/08). During this time Worker 2 is assisting by "looking at the computer and calling out the count rate."

	Testimony from Worker 2 only mentions observing that Worker 1 placed the glass-bottled source, in its metal can, in front of the detector. Worker 1 reports that he may have touched the glass-bottled source to the nearby lead bricks or detector housing during this operation. (In revised statements, this action might have occurred later.) Having located the “optimal position” for the source, Worker 1 recalls replacing the glass-bottled source into the metal can. He reports that the glass-bottled source lies on top of plastic bags in the can and is leaning against the interior wall of the can.
14:49	Data acquisition begins — no counts recorded by detector
15:02	Data acquisition system begins to record pulses by the detector (indicating that source is close to detector).
~ 15:00	Worker 2 leaves the lab around this time, shortly after beginning data acquisition, but before Worker 1.
15:08	NIST Boulder security camera shows Worker 1 entering his office from the direction of Wing 1 (direction of laboratory 2124)
*****	***Actions listed below by Worker 1 (under “Unknown Time” - see below) are reported by him to have occurred at this time, i.e. shortly after starting data acquisition. However, this sequence of events reported to have occurred at this time are incompatible with video, computer, and other testimony. We conjecture that the actions reported by Worker 1 actually occurred sometime around 15:45 and are shifted accordingly in this timeline. Therefore times given in Worker 1 statements differ by 45 minutes to 1 hour from the timeline from this point forward. (This conjecture is later confirmed by Worker 1).***
15:38	Security camera logs show Worker 1 leaving office for direction of Wing 1.
Unknown*	Worker 1 reports noticing that the glass-bottled source is “cracked”. In his original interview with the HP-GL, he reports that the glass-bottled source was in its plastic bag. He states that he believes that the glass-bottled source could have tipped over in the can while moving it during the set up. Worker 1 reports covering metal can containing the damaged glass-bottled source with tape and then returning it to the storage cabinet.

	Worker 1 reports returning to detector area to retrieve lab notebook. In his revised statement, Worker 1 reports washing hands in sink, as a "precautionary measure." He reports in some detail that he: "put the lab book on the left side of the sink while washing. He washed with soap and the scrubber twice and dried with a paper towel from the right side of the sink. He threw the towel into the dustbin to the right of the sink, picked up the book, and walked into Lab 3 (Rm. 2114) to talk to [the PI]." Worker 1 goes to room 2114 to tell the PI that "he might have seen a crack in the sample [glass-bottled source]." The PI tells Worker 1 that he'll take a look, but does not immediately get up to do so. Worker 1 leaves 2114 goes towards his office. The PI goes to lab 2124 to investigate after completing a brief (~5 minute) conversation with a coworker.
15:43	Detector stops recording pulses, but the detector system is still on.
15:52	Detector resumes recording pulses, but at a slightly reduced rate.
~16:00	During interview with the PI he states that Worker 1 enters the lab to tell the PI that he "thought there was a crack in the source [glass-bottled source] and he put it into the drawer" (i.e. of the storage cabinet).
16:00	Security cameras record Worker 1 entering office from direction of Wing 1.
16:02	Security cameras record Worker 1 leaving office and enter stairwell.
~ 16:00	Worker 1 calls Worker 2 (from his office) wanting to discuss data (noise spectrum). Worker 1 visits Worker 2's office. Standing just inside door they have brief (4-5 minute) discussion.
~ 16:00	The PI goes to lab 2124 to inspect the glass-bottled source. He reports going to storage cabinet to retrieve source and was confused about which source to examine. The PI states that he does not recall calling Worker 1, but does state that Worker 1 returned to the lab to identify the correct source in the drawer of the storage cabinet. (In a later statement, the PI states that he believes he was inspecting the undamaged CRM 137 source during the time before Worker 1 returned to the lab.)
16:10	Security cameras record Worker 1 and Worker 2 entering office of Worker

	1.
~16:10	Worker 1 and Worker 2 have brief (~ 5 minute) discussion about data while looking at computer screen. Worker 2 recalls not touching anything on the desk. The PI phones Worker 1 and asks him to return to laboratory 2124. Worker 2 recalls that Worker 1 tells him that he had "earlier checked the progress of the measurement and had noticed that the glass around the sample [glass-bottled source] appeared to be cracked."
16:13	Security cameras record Worker 1 and Worker 2 leaving Worker 1 office towards Wing 1.
~ Between 16:15 and 16:45	Worker 1 and Worker 2 enter lab 2124 and find the PI at table near the radioactive source storage cabinet. The PI asks Worker 1 about which source he thought was cracked. Worker 1 reports that the PI is inspecting the "wrong source" when he enters the lab with Worker 2. Worker 1 shows the PI a source located in the storage cabinet drawer. It has an opaque layer of tape covering the metal can. The PI asks about the tape over the metal can. Worker 1 says that he placed it there. The PI cuts open tape and looks inside can. The PI reports that he observed "brown powder" on the outside of the plastic bags but that he cannot see the condition of the glass-bottled source. He states that this is a "serious incident." He reports replacing the metal can in the storage cabinet drawer and asking everyone to immediately leave the lab. The door to the lab is closed at this point. The PI reports that, working alone, he puts on gloves, removes the can from the safe, spreads a sheet of aluminum foil on a lab bench near the storage cabinet, places the metal can on the foil, inspects the contents, places the contents into two ziplock plastic bags, and then returns the glass-bottled source to the storage cabinet drawer. The PI reports folding up the aluminum foil (contaminated side inward) and placing it in the storage cabinet. The PI reports that during the inspection he can see the glass-bottled source and notices for the first time that the bottom is broken off and completely separated from the rest of the glass bottle. The PI reports calling the B-RSO and leaving a message. The PI calls the

	B-RSO cell and leaves voice message. The PI sticks head out of the door to the lab and tells Worker 1 and Worker 2 that "this is serious." Worker 1 re-enters lab with the PI. The PI asks Worker 1 to put on gloves. They then take a gamma counter (Rad Monitor 4) and survey the area near the detector. The PI reports a "high reading" on the survey meter and reports seeing a brown powder on the table and floor. Worker 1 does not report seeing any powder. Worker 1 and the PI evacuate the lab. [Subsequent entries by HP staff report not seeing any powder on the counter but confirm substantial surface contamination in this area and on the floor.]
16:29	Detector system stops recording counts Later interviews report that Worker 1 stopped the data acquisition (by a mouse click on the control computer) at roughly the same time that the PI reported seeing the brown powder. This was also about the time that the PI makes survey measurements with a gamma counter and observes a "high reading."
~ 16:45	The PI calls the Project Leader and requests that he come to the lab. The Project Leader responds immediately and leaves his office to head to the laboratory. (Witnesses observe the Project Leader walking to the lab in a hurry.) The Project Leader enters lab and talks to the PI and Worker 1. They describe the serious situation. The Project Leader and the PI begin calling for assistance. At some point during this period, a suggestion is made for people to remove their shoes in order to avoid spreading contamination.
16:45	A phone call is made from the PI to the OSHE Safety Engineer reporting "a small plutonium spill in B1-2124." The OSHE Safety Engineer tries to contact the B-RSO (via cell, home, and Nextel). The OSHE Safety Engineer calls the OSHE Director. The OSHE Director asks "How a sealed source can spill?"
16:47	A phone call is made from the Project Leader to the Division Chief and a message is left. Statements also indicate that the Project Leader may have called the Group Leader.
16:51	Email from the Division Chief to the Project Leader: "I am in CPEM

	sessions and can't check voice mail, but can read email if urgent."
16:52	The OSHE Director calls the PI on his cell. The PI describes a "plutonium spill" and that the lab has been "sealed." The OSHE Director describes efforts to locate the B-RSO and says she will return to lab if the B-RSO cannot be located. Based on information from the OSHE Director that the B-RSO (or any other safety staff) may not be responding immediately, the Project Leader contacts the Boulder Director and requests assistance. The Boulder Director immediately comes to the lab.
16:56	The OSHE Safety Engineer calls EMSS via radio who directs her to a point of contact to shut down air handling unit.
17:02	The OSHE Director calls the OSHE Safety Engineer. The OSHE Safety Engineer relates that she contacted EMSS and had them instruct the PI on shutting down the air handling units in the lab.
~17:15	The B-RSO calls the OSHE Safety Engineer and says he is headed into NIST. His estimated time of arrival is approximately ½ hour.
17:15	EMSS contacts the PI and instructs him on finding breaker box to shut down the fan unit in lab 2124. The PI reenters lab 2124 and shuts down fan unit.
~ 17:30	The B-RSO calls the PI and tells him that he is on the way in. The B-RSO tells the PI to collect everyone who was potentially in the lab. A suggestion is made to survey with an alpha sensitive survey meter. The PI re-enters lab to retrieve alpha meter. Responding lab personnel start surveys with alpha probe and begin to detect contamination on shoes and on floor outside laboratory. Responding lab personnel begin to contact everyone who thought they were in the laboratory that day and begin a list on a nearby whiteboard.
~18:00	The B-RSO arrives on scene and assumes control over response.

Additional findings:

- The large number of witness accounts, repeated interviews, and the high stress that followed these events results in some inconsistencies in the statements from the various participants. This is understandable. Significant effort was made to re-interview key participants to clarify or expand on details. The chronology presented here is our best effort to reconstruct events based on available testimony combined with the physical evidence provided by the security cameras, computer logs, and the results of inspections and surveys of the laboratory following the spill.

- Statements indicate that during the experimental set up Worker 1 and Worker 2 repeat the optimization process discussed on Friday (June 6). This process involves directly holding the glass bottle with the plutonium source and moving it in front of the detector to optimize the count rate. Because Worker 1 and Worker 2 are working together, Worker 1 is able to move the glass-bottled source while Worker 2 calls out the count rate information.

- During the experimental set up, Worker 1 reports positioning lead bricks into the experimental area. The stated purpose is to protect a nearby computer from "crashing". This action increases the clutter of solid objects in the vicinity of the experiment. (See photograph of experimental layout in Figures A1 and A2.)

- The evidence available concerning the start of the experimental run at approximately 15:00 did not suggest that visible damage has occurred to the glass-bottled source. Data acquisition had begun, Worker 2 and Worker 1 were working together, and their subsequent behavior did not suggest that there were any problems at this point. Similarly, computer logs show that the detector recorded a steady count rate from the start of the experiment at 15:02 until 15:43. Also, security camera logs showed that Worker 1 arrived at his office at 15:08, only six minutes after starting the run. This conflicts with early testimony from Worker 1 (revised on July 1) that he noticed the potential damage to the glass-bottled source at this time and began to take corrective actions (e.g. taping the lid and placing it in the storage cabinet). We believe that these actions would likely take longer.

- Based on the observed detector count rates and timeframe, it appears that the glass-bottled source was intact before Worker 1 returns to the lab at 15:38.

- Based on the observed detector count rates, timeframe, and contamination survey results, it appears that the glass-bottle sample was compromised during the period that the detector counting rate decreases between 15:43 and 15:52.

- If Worker 1's earlier testimony is adjusted to this timeframe, then the subsequent actions he reports are roughly consistent with other testimony and available physical evidence. In subsequent statements and interviews, Worker 1 reports that he noticed the damaged glass-bottled source upon returning to the lab the second time (approximately 15:38).

- Radiation survey results made after the incident showed very significant levels of contamination on the counter where the glass-bottled source was being used for count rate measurements and on the floor adjacent to the detector, indicating that the glass-bottled source was compromised and contamination released.

- Radiation survey results made after the incident do not show extensive contamination on the handles of the drawers to the storage cabinet or inside the cabinet.

- Worker 1 reported that after noticing that the glass-bottled source was "cracked" while in its can, that he taped the can shut with scotch tape located near the workbench (confirmed by inspection of the lab) and then placed the sealed can into the storage cabinet. However, the findings of substantial contamination at the work bench are inconsistent with a cracked but intact glass-bottled source.

- Testimony from Worker 1 reports that he then placed the can with the damaged source into the storage cabinet.

- The data acquisition computer begins to record counts from the detector at a reduced count rate at approximately 15:52 (10 minutes after stopping). Worker 1 has stated in a later interview that the resumption of counts must have been from the other (undamaged, but identical) CRM 138 glass-bottled source. This suggests that Worker 1 took the undamaged CRM 138 glass-bottled source and placed it at the detector shortly after placing the broken CRM 138 glass-bottled source in the drawer.

- Worker 1 reports in revised testimony that he washed his hands "as a precaution" after noticing the cracked glass-bottled source. Again through testimony, Worker 1 states that prior to exiting the laboratory, that he placed his contaminated lab notebook on the edge of the bonder table and washed his hands in the sink at the front of the laboratory. Radiation survey results made after the incident show significant levels of contamination in the sink and lower levels at the bonder table.

- From a risk perspective, washing was likely fortuitous because he was not wearing gloves, if he had not washed the very high levels of contamination that was probably on his hands would have greatly increased both the potential for internal uptake of plutonium by Worker 1 and the spread of contamination to other areas. On the other hand, the failure to contain the wash water caused an unmonitored release of radioactivity down the drain.

- Worker 1's testimony and other accounts support that he left the lab to make a report to the PI that the glass-bottled source may be damaged. Worker 1 does not communicate the incident or the conditions in the lab to anyone else besides the PI. He then proceeds to his office to discuss findings with Worker 2.

- The PI enters the lab to investigate, probably around 16:00 or shortly afterwards. He opens the storage cabinet and inspects the wrong, intact glass-bottled source. He is confused and calls Worker 1 in his office and asks him to return to the lab.

- Upon Worker 1's return, the PI asks "which sample [glass-bottled source]?" Testimony supports that the correct (i.e. damaged) glass-bottled source was then retrieved from the storage cabinet.

- The PI opens the can by cutting through the tape and finds evidence of a damaged source bottle, including seeing brown powder. He clears the lab.

- After the lab is clear, the PI proceeds to further inspect the contents. At this point he observes that the glass-bottled source is completely broken. The glass-bottled source was then repackaged into plastic bags (found near the work area), and returned to the storage cabinet.

- The PI begins a notification process to the B-RSO, the OSHE, and management.

Figure A1. Laboratory 2124 showing the contaminated detector area. The detector is the rectangular device on the white bench in the left-center of the picture. The control computer is located in the electronics rack shown in the left side of the picture. The source position is located between the detector and the electronics rack and is not visible in this photograph.

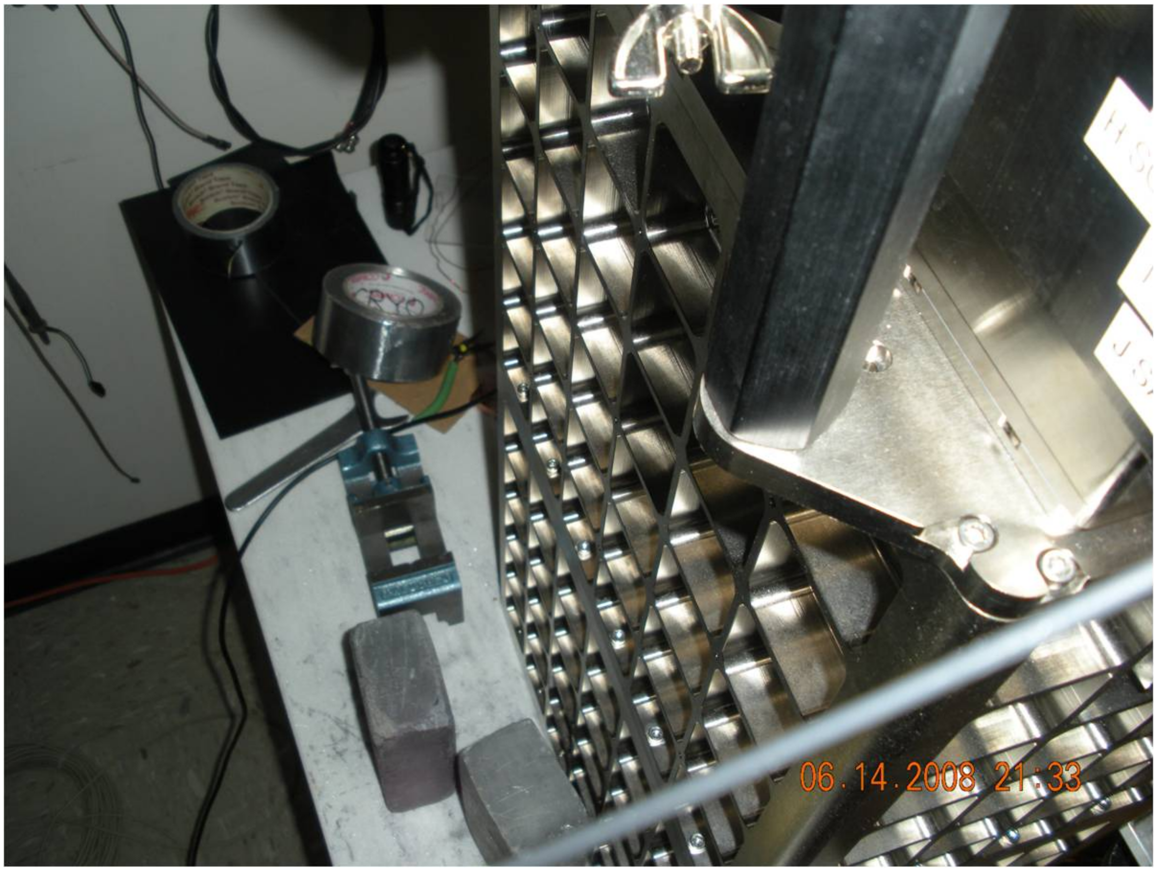

Figure A2 The source position in front of detector. This area is located between the detector and the electronics rack. Shown are the lead bricks and the vice used to position the source.

Figure A3 Broken CRM 138 source bottle (shown inside multiple plastic bags). The broken bottom of the bottle is visible in the upper right hand corner.

Figure A4. Fire-proof, radioactive source storage cabinet (shown during entry to the contaminated lab). Other glass-bottled source and lead bricks can be seen in the drawer.