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Abbreviations and Acronyms

ABRWH, Board	Advisory Board on Radiation and Worker Health
A	assumed
Am	americium
Am/Cm/Cf	americium/curium/californium
bios	bioassays
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DOE-SR	DOE Savannah River Operations Office
CTW	construction trade worker
DPSOL	DuPont Savannah River Operating List
DPSOP	DuPont Standard Operating Procedure
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ER	evaluation report
EU	enriched uranium
FEB	Facility Evaluation Board
GAO	U.S. General Accounting Office
HHS	U.S. Department of Health and Human Services
HQ	headquarters
JSB	job-specific bioassay
mrem	millirem
NA	not applicable
NIOSH	National Institute for Occupational Safety and Health
Np	neptunium
NTS	Noncompliance Tracking System
ORAUT	Oak Ridge Associated Universities Team
PAAA	Price-Anderson Amendments Act
Pu	plutonium
Q2	second quarter
R	required
RIP	Radiological Improvement Program
RCA	radiologically controlled area

RCO	Radiological Control Operations
RQB	radiological qualifications badge
RU	recycled uranium
RWP	Radiological Work Permit
sCTW	subcontractor construction trade worker
SAR	safety analysis report
SEC	Special Exposure Cohort
Sr/FPs	strontium/fission products
SRDB	Site Research Database
SRS	Savannah River Site
SRTC	Savannah River Technology Center
SRWP	standing radiological work permit
STC	special tritium compound
U	uranium
WG	work group
WSRC	Westinghouse Savannah River Company

1 Executive Summary

SC&A, Inc. reviewed the National Institute for Occupational Safety and Health (NIOSH) Special Exposure Cohort (SEC) Petition SEC-00103 evaluation report (ER) for the Savannah River Site (SRS) for the period 1991–2007. Following the designation of an SEC class for subcontractors 1972–1990, this review encompasses the remaining years that were qualified for that SEC evaluation and also addresses any remaining SEC-relevant issues stemming from previous discussions of the SRS and SEC Issues work groups.

SC&A approached this review by considering to what extent the programmatic shortcomings that impaired job-specific bioassay monitoring at SRS during the prior SEC period were remedied by the major procedural upgrades undertaken by the new operating contractor, Westinghouse Savannah River Company (WSRC), and in what timeframe. Bioassay data completeness, itself, was addressed in terms of the degree to which job-specific bioassays were performed, either *directly* or *effectively*, in the context of the data sampling in ORAUT-RPRT-0092, revision 00, "Evaluation of Bioassay Data for Subcontracted Construction Trade Workers at the Savannah River Site" (NIOSH, 2019a; "RPRT-0092"). Reconciling program assurance and data completeness measures is necessarily subjective: weighing when job-specific bioassay monitoring became reliable and complete enough that resulting datasets can be considered representative of subcontractor exposures. SC&A's objective is to present the full scope of these considerations for work group deliberation, understanding that the actual weighing and balancing of them will ultimately be performed by the work group and the Advisory Board on Radiation and Worker Health (Board).

For program assurance, SC&A examined key elements of the job-specific bioassay monitoring program for which concerns were raised for the earlier SEC period (1972–1990). These include implementation of a functional Radiological Work Permit (RWP) program, reliable collection of job-specific bioassays, and sufficient facility source-term characterization to identify radionuclides of concern.

While RWPs were introduced in phases by corrective action following the Tiger Team assessment, beginning in mid-1990, and subsequently codified by procedure in 1992, SC&A finds that adequate implementation of these requirements was not apparent in the workplace until 1994–1995. SC&A found that the fraction of required bioassays as listed on the RWPs rose from very few (less than 5 percent) in 1991–1993 to over 60 percent in 1994 and over 80 percent in 1995. As with the earlier SEC period (1972–1990), NIOSH did not address all the radionuclides mandated for the RWP when determining data completeness for job-specific bioassay monitoring. Rather, the summary conclusions in NIOSH's RPRT-0092 evaluation of subcontractor bioassay data (NIOSH, 2019a) assessed whether at least one radionuclide mandated for an RWP had been monitored adequately, as shown in table 6-4 of that document. Therefore, the percentage of *matching* results for *direct* and *effective* monitoring appear to be overstated. This is most relevant for the 1991–1994 period, when many exposure-relevant radionuclides of concern were not yet included in RWPs (with the balance being predominately prescheduled), and inaccurate facility source term assumptions may have been made, as noted by the U.S. Department of Energy (DOE) in 1990 (DOE, 1990) and by WSRC in 1999 (WSRC, 1999a).

Concerning co-exposure model datasets, SC&A's focused review of plutonium coworker matches during the 1991–1998 WSRC period in RPRT-0092 found that, while nearly 96 percent of identified coworker matches involved the same RWP, inclusion of additional criteria (e.g., the same date, time, and craft) decreases this percentage significantly, down to 45 percent (SC&A, 2019a, p. 60). Given the often nonroutine and intermittent nature of subcontractor construction trade worker (sCTW) jobs under RWPs, sometimes involving unique radiological source terms, SC&A believes that matching needs to be more closely aligned with what is cited on the actual RWP.

Notwithstanding the bioassay sampling matches provided for 1991–1998 in RPRT-0092 and the amount of routine bioassay data available for SRS, WSRC found, in 1997, that required job-specific bioassays were not being submitted by most workers (e.g., 79 percent missing in the second quarter of 1997) (DOE, 1998a). Assuming that similar lapses in bioassay submission existed during the 1991–1996 timeframe (spanning from the initial 1990 Tiger Team findings about bioassay program noncompliance to the 1997–1998 WSRC actions in response to DOE field audits, internal Facility Evaluation Board (FEB) findings, and DOE headquarters enforcement action), RWP-required job-specific bioassay data should be assumed to be substantially incomplete for purposes of demonstrating monitoring data completeness and representativeness for use in a co-exposure model until the end of 1996. A 100-percent resampling of all workers on job-specific bioassays was performed for 1997, and enhanced accountability and tracking of job-specific bioassays were implemented in 1998.

While job-specific bioassays and source terms may be incomplete given these programmatic shortfalls, this is mitigated by considerations such as (1) job-specific bioassays made up only 5 percent of total bioassays[1] and (2) a full resampling of job-specific bioassay results for the second quarter of 1997 found no evidence of intakes. Likewise, a sampling of RWPs during this same period indicates that many workers were either directly monitored or on the same RWP as an assumed coworker who was monitored, which resulted in their being effectively monitored. The majority of these monitoring results are presumably a result of enrollment in the routine program and thus do not obviate the deficiencies in completeness of the job-specific monitoring program. However, it must be determined if, and when, the observed coverage of the routine monitoring program is sufficient to justify the representativeness of any subsequent co-exposure model as applied to workers who should have been covered by the deficient job-specific program.

One potential SEC question that persists is the appropriate scope of construction trade workers (CTWs) that can and should be addressed by existing co-exposure models. The distinction between sCTWs and CTWs in terms of work activities and exposure potential has been sometimes clouded during recent deliberations before the work groups. NIOSH concluded that "the exposure conditions and the potential for intakes were similar among all CTWs (prime and subcontractor), therefore a combined strata [for co-exposure modeling] is appropriate" (NIOSH, 2020a, slide 21). SC&A contended that subcontractor radiological work would have been more intermittent and transitory in nature and likely involved more nonroutine, high-exposure

[1] As found by a WSRC self-assessment of the internal monitoring program participation for the first four months of 1997, although this one-time sampling is not necessarily applicable to earlier years (DOE, 1998a).

activities and source terms. Overall, the lack of compliance with the program that should have provided job-specific bioassay monitoring would have impacted CTWs on job plans and RWPs, the same as for sCTWs. From an exposure potential standpoint, should CTWs on permit-directed, job-specific bioassays be within the scope of SEC consideration? While the nature of subcontractor work under RWPs was compelling as a basis for the SEC recommendation for 1972–1990, the programmatic and operational circumstances of broader CTW exposure potential during 1991–2007 needs to be reexamined for consistency.

Regarding other SEC-relevant issues for SEC-00103, SC&A has found no outstanding issues other than several remaining action items for work group discussion and closure from previous issues matrices (these are listed and updated in attachments A and B).

2 Introduction

SC&A was tasked by the Board's SRS Work Group on September 21, 2021, to review NIOSH's SEC-00103 ER for the period 1991–2007, with a focus on remaining SEC-related issues stemming from RPRT-0092 (NIOSH, 2019a). The Board recommended, and the Secretary of Health and Human Services (HHS) approved, that an SEC be designated for:

> All construction trade employees of Department of Energy subcontractors [excluding employees of the following prime contractors who worked at the Savannah River Site in Aiken, South Carolina, during the specified time periods: E. I. du Pont de Nemours and Company, October 1, 1972, through March 31, 1989; and Westinghouse Savannah River Company, April 1, 1989 through December 31, 1990], who worked at the Savannah River Site from October 1, 1972, through December 31, 1990, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort. [ABRWH, 2021, p. 1; HHS, 2021, p. 2]

The basis for this recommendation for 1972–1990 acknowledged that subcontractors conducted a broad range of work activities at SRS and may have worked in high-contamination and high-airborne-radioactivity areas and may have been utilized for short-term high-exposure work tasks (ABRWH, 2021). It was also found that subcontractors may have been "transient" and "intermittently tasked with nonroutine radiological jobs under work permits, and thus were not likely enrolled in the routine (including termination) bioassay monitoring program" (ABRWH, 2021, p. 1). The Board also found there to be "insufficient information, including a lack of job-specific radio-bioassay monitoring data for subcontractor construction trade workers, and assurance of workplace monitoring and source term data, to enable NIOSH to estimate with sufficient accuracy all potential internal doses" (ABRWH, 2021, p. 2).

The purpose of this review is to assess these same programmatic and bioassay data adequacy issues for post-1990 operations at SRS, during the balance of years covered by NIOSH's ER (1991–2007) for the SEC-00103 petition, to ascertain whether these inadequacies may have persisted into that later time period and to assess to what extent, and to what point in time, dose reconstruction with sufficient accuracy may have been affected.

SC&A revised the last SEC issues matrix (SC&A, 2014a) compiled for the work group to update the status of the remaining SEC-relevant issues. This matrix was issued as a memorandum to the SRS and SEC Issues work groups on March 11, 2022 (SC&A, 2022), and is reproduced for convenience here as attachment A.

SC&A also addressed the status of remaining SEC-00103 issues that remain before the work group, including those stemming from the co-exposure model reviews and radionuclide-specific issues (e.g., neptunium, thorium, and metal hydrides). NIOSH and SC&A have already exchanged reviews and responses for these issues and await work group discussion and closure.

SC&A provided the work groups an internal status update for these issues in a matrix on October 25, 2021 (SC&A, 2021), reproduced here for convenience as attachment B.[2]

[2] Note that the attached version of the matrix has been modified slightly for accuracy following a subsequent conference call meeting between SC&A and NIOSH on January 12, 2022.

3 Background

As emphasized by SC&A in its past reports and presentations, the period of time between the mid-1980s and early 1990s was one of rapid operational, policy, and program changes at SRS, as well across DOE's other nuclear facilities. In response to external events, such as the Chernobyl nuclear accident in 1986 and outside scrutiny of the environmental protection compliance of its operations, DOE opened its facilities to independent regulation on the environmental side and developed updated environment, safety, and health directives, including DOE Order 5480.11, "Radiation Protection for Occupational Workers," in 1988. This was coupled with independent DOE headquarters assessments for safety and health, including DOE-wide audits beginning in the mid-1980s, followed by headquarters-managed Tiger Teams that audited environment, safety, and health program compliance beginning in 1989. At the same time, Congress held a series of hearings and investigations about the conduct of nuclear and radiological safety programs at DOE's nuclear facilities, culminating in legislation forming external oversight bodies for DOE nuclear facility oversight, consisting of the Advisory Committee on Nuclear Facility Safety in 1987, which was supplanted in 1998 by the Defense Nuclear Facilities Safety Board. The Price-Anderson Act was amended in 1988 to establish a formal regulatory enforcement program for nuclear facility safety within DOE, to be administered by an independent headquarters office. The implementation of a DOE-wide enforcement program ushered in a regulatory version of the DOE occupational radiation protection directive, Title 10 of the Code of Federal Regulations (CFR) Part 835, which was promulgated in 1995.

At SRS, during this same time period, these major departmental changes were compounded by unprecedented changes in site operations, management, and policy. Following an anomalous spike in reactor power during startup of P Reactor in 1988, internal investigations and congressional oversight hearings led to shutdown of and upgrades to the SRS production reactors through the early 1990s. With the end of the Cold War, the tritium production mission of SRS was replaced by other missions, including those of facility decontamination and decommissioning, waste management, and expanded research. These changing and expanded missions prompted the influx of increasingly large complements of outside sCTWs, which peaked in the late 1980s to early 1990s.

DuPont ended its 38-year contractual management of the SRS site on April 1, 1989, and WSRC became the operating contractor (with Bechtel as the construction management contractor). On the heels of the Tiger Team assessment of SRS in early 1990, WSRC embarked on a Radiological Improvement Program (RIP) to revise sitewide radiation protection procedures, expand the qualifications and training of personnel, and improve actual workplace safety compliance. The scope of the RIP, begun in late 1990, encompassed functions of the radiological monitoring program critical to the SEC-related questions at hand. These included RWPs, job-specific bioassays, termination bioassays, facility source-term characterization, and applying bioassay requirements to *roving employees* (those whose job assignments had them entering various radiological facilities).

WSRC was given a notice of violation and a civil penalty in 1998 under the Price-Anderson Amendments Act nuclear safety enforcement program. The citation was for "deficient work processes with respect to full worker adherence to established WSRC bioassay requirements" (DOE, 1998a, p. 1). DOE's Office of Enforcement and Investigation found that:

> Specifically, workers and their management **routinely failed**, over a period of approximately two years, to ensure that job-specific bioassay samples were submitted for analysis as required by WSRC internal procedures. DOE-SR identified bioassay sample submittal deficiencies for the job-specific portion of the bioassay program to WSRC **as early as November 1995**. . . . In spite of these completed corrective actions that included numerous revisions to bioassay and work control procedures and worker retraining, **worker participation in the job-specific bioassay program continued to decline**. These violations occurred because WSRC did not have a process in place to determine whether corrective actions had been effective in remedying identified deficiencies. As a consequence, the job-specific bioassay non-participation level rose to **79 percent in the second quarter of 1997.** [DOE, 1998a, pp. 1–2; emphasis added]

This notice of violation originated in a self-assessment conducted by WSRC in May 1997, subsequent to its initial findings in 1995, following DOE enforcement actions in 1997 at Mound Laboratory for a similar lack of adherence to job-specific bioassays. The intent was to determine if similar problems existed with the bioassay program at SRS (*Augusta Chronicle*, 1998). WSRC conducted its earlier, limited sampling of facilities using job-specific RWPs requiring bioassay samples and found that:

> Of the 3,200 bioassay requirements reviewed, 95 percent of the workers were covered by the routine bioassay program and had submitted bioassay samples as required. However, of the 5% of the workers requested to submit job-specific bioassay samples, only 33% [non-participation rate of 67%] were provided. A separate review also found that the Bioassay Laboratory was only notified by the Radiological Control Operations (RCOs) of about 33% of the samples that were actually submitted for analysis. [Cite redacted]

As noted in its initial review of job-specific bioassay data completeness in 2017, SC&A found that "the problem of worker and management adherence to job-specific bioassay requirements was a persistent one, as far back as to the 1990 Tiger Team assessment" (SC&A, 2017, p. 17). Corrective actions tied to the Tiger Team assessment in 1990, and later WSRC findings in 1995 and 1997, proved inadequate to change the workplace culture and accountability to bioassay participation. WSRC's later corrective actions included extensive revision of existing procedures to strengthen accountability measures for job-specific bioassays, to expand worker training, and to develop lines of inquiry to be added to WSRC self-assessments of safety and health operations ([redacted]).

The timing and realization of these upgrades provide the basis for programmatic assurance that subcontractors performing radiological work under a permit would have been appropriately bioassayed for radionuclides for which they had an internal intake potential. *Realization* is used here to contrast with mere implementation, because the longstanding DuPont era workplace safety culture surrounding radiological controls at SRS would not have changed immediately with either the advent of a new operating contractor or implementation of the RIP. Instead, it was recognized by both DOE and WSRC as a long-term process that would take some years before being realized (GAO, 1990). This question—when and how SRS radiological monitoring of sCTWs became adequately reliable and complete in the 1990s for purposes of dose

reconstruction under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA)—is addressed in the following sections from a programmatic and data completeness standpoint.

4 Review of WSRC Programmatic Assurance for Subcontractor Bioassays, 1991–2007

4.1 SRS internal monitoring dosimetry program procedural upgrades, 1991–2007

A detailed summary of the evolution of policies and procedures during most of the early years of this period (1971–1999) can be found in section 3.0 of NIOSH's report, ORAUT-RPRT-0091, revision 00, "Evaluation of Savannah River Site Americium-241 Source Terms Between 1971 and 1999 Using Bioassay Frequency Tables" (NIOSH, 2019b; "RPRT-0091"). For SRS facilities, WSRC prescribed a system of routine, special, and job-specific bioassay monitoring,[3] with worker categories, frequencies, and facility areas defined in the successive revisions of DuPont's DPSOL 193-302 beginning in the 1960s (DPSOL 193-211 in 1988) and in Manual 5Q1.1, beginning in 1992. Construction Division workers were not required to use the bioassay sample frequency tables and had more general requirements until the initial 1992 Manual 5Q1.1 procedures were implemented, upon which in vitro and in vivo bioassay procedures were applied in the same manner to all SRS workers (WSRC, 1992, p. 28).

The following are policy and procedural milestones in the WSRC bioassay program relevant to the question of nonroutine, job-specific bioassay data completeness after 1990.

Radiological Work Permits (RWPs). SC&A (2019a) noted in its review of RPRT-0092 that:

> The RWP program was discontinued in the 1960s by DuPont in favor of applying internal DPSOL procedures, but as a DOE assessment pointed out, a requirement for RWPs and SRWPs [standing RWPs] for any work within a radiologically controlled area (RCA) was carried forward as cited in Special Hazards Bulletins in DPSOP 40, revision 82, September 1989. As DOE observed, "Radiation Work Permits or Standing Radiation Work Permits are not used even though required by Westinghouse Savannah River Company procedures and accepted industry standards" (DOE, 1990, p. 4-307). [SC&A, 2019a, p. 34]

In response, WSRC began phasing in its RWP procedures across SRS in the 1990–1991 timeframe, although it is not clear how and on what timeframe that implementation was carried out (WSRC, 1990a). Notably, there was only one RWP identified in RPRT-0092 for 1990, with increasing numbers in 1991. The RWP procedures were subsequently codified in the initial 1992 version of WSRC Manual 5Q1.1. The importance of a sitewide, fully functional RWP program cannot be overstated. Without RWPs, there would not have been an accountable and deliberative process by which potential nonroutine radiological hazards, including unique radionuclide source terms, would have been assessed to determine what job-specific bioassays would have been

[3] By the late-1990s WSRC era at SRS, the routine bioassay program was defined in two parts: "The **pre-scheduled** sampling program includes workers who routinely work in locations with Airborne Radioactivity Area postings. They are sampled twice annually, based on their birthday, for those radionuclides they routinely encounter. . . . The **job-specific** sampling program is for workers not on a routine program, or **whose routine program does not cover all the radionuclides to be encountered**, but who need to enter locations requiring respiratory protection" (WSRC, 1998a, p. 1; emphasis added).

warranted to adequately monitor the worker for potential job-specific intakes. Without necessary job-specific bioassays being specified, the resulting data (i.e., bioassay dataset) would be incomplete and not necessarily representative of the potential exposures attendant to nonroutine radiological work being conducted at SRS.

Roving employee coverage. Notable in the initial 1992 version of Manual 5Q1.1 is a new guideline defining some workers as "Roving Employees," whose "job assignment requires them to enter RCAs in different facilities across the Site during the course of their regular work" (WSRC, 1992, PDF p. 37). This new definition specifically included site support personnel and subcontractors, who by the nature of their work and craft tended to move from location to location at SRS. For the first time, it was required that such workers be categorized for bioassay type and frequency according to which SRS facilities they spent the majority of their time and be placed on a "composite" bioassay program (WSRC, 1992, PDF p. 37). Before this new procedure, it had been up to individual facility managers to determine whether and what bioassay requirements would apply to such transient workers in their facilities, leading to potential inconsistencies in bioassay coverage in terms of source terms, type, and frequency. A fully implemented RWP program, coupled with a computer-controlled access system in 2003/2004, made it feasible to ascertain which workers were monitored and in what location (LaBone & Findley, 2013).

Respiratory protection linkage. Another explicit requirement was added in the Routine Bioassay Program Assignment section of Manual 5Q1.1, revision 0, which entailed that "Personnel who wear respiratory protection or who work in posted Contamination or Airborne Radioactivity Areas must be sampled for the nuclide to which they are potentially exposed, via either the routine sampling program or non-routine, job-specific sampling program" (WSRC, 1992, PDF p. 60). This was the first formal referencing of a requirement that linked respiratory protection use with the need for either routine bioassays or nonroutine, job-specific bioassays.

Job-specific bioassays. WSRC considered it also necessary to include, in the initial 5Q1.1 manual, an admonition about the importance of performing nonroutine, job-specific bioassays and combining them with the routine bioassay program:

> **Caution:** It is **EXTREMELY IMPORTANT** to note that the effectiveness of the bioassay program in general depends on combining both the routine and the non-routine, job-specific program. Any time unusual events occur, or jobs are performed that may expose personnel to unusual hazards, a job-specific program should be considered per Section 5.1.2.1. [WSRC, 1992, PDF p. 36]

As noted in SC&A's review of RPRT-0092, "Without job-specific bioassays to complement the required plutonium, tritium and fission product routine bioassays, "roving" construction workers would not have been adequately enrolled for the radionuclides to which they may have been potentially exposed, and the bioassay database for both CTWs and subCTWs would accordingly be incomplete" (SC&A, 2019a, p. 21). Regarding reliance on the routine bioassay program, WSRC made it clear that unique job-related radiological sources entailed job-specific bioassay sampling:

> It is very important to realize that being on a routine sampling program does not automatically cover the bioassay sampling requirement specified on the RWP. In fact, section 5.2.4 of 5Q1.1, 504 "Radiological Work Permit" used to require that the radiological control supervisor identify the RWP bioassay requirements so that they were consistent with 5Q1.1, 506 "In Vivo and In Vitro Bioassay Scheduling and Administration." This link was eliminated because routine sampling programs may not be appropriate for work involving non-routine mixes or concentrations of radioactive material. [Findley, 1997, p. 2]

The distinction between routine and non-routine bioassay sampling is important to the question of bioassay data representativeness and whether and how SRS routine bioassay data can be substituted for what may be incomplete nonroutine bioassay data related to job-specific bioassay sampling. It also shows that WSRC continued to have programmatic shortcomings in how job-specific bioassays were being implemented as late as 1997.

Termination bioassays. Included in the initial 1992 5Q1.1 manual was an expanded procedural requirement for termination bioassays for all employees who were being monitored on in vivo or in vitro bioassay programs (WSRC, 1992). This would have explicitly included transient sCTWs on RWP-directed, job-specific bioassays, given the requirement to consider both routine and nonroutine bioassay programs. In the DuPont era, facility managers would have identified workers for termination bioassays, a process made difficult by the transient nature of some sCTWs, the roving nature of their work, and the lack of responsiveness by some workers to performing a termination bioassay before leaving the site. However, despite the addition of the 1992 requirement, WSRC's self-assessment in 1999 found that there continued to be a "Failure to perform termination bioassays and, subsequently, failure to issue reports of terminated worker exposures" (WSRC, 1999b, p. 5). An adequate termination bioassay program was not realized until the 1999 response to this finding, which entailed the implementation of "new radiological compliance requirements so that adequate subcontractor tracking information is provided . . . The new requirements are more specific and detailed, and include possible future work restrictions for subcontract employees who fail to comply with radiological requirements at termination" (WSRC, 1999b, p. 5). The implications of not having an adequate termination bioassay program for subcontractors are clear: If internal monitoring was missed due to inadequate RWPs or incomplete job-specific bioassay submissions, any uptakes and potential internal dose would not have been necessarily caught at termination.

Facility source-term characterization. In 1999, WSRC prescribed a detailed facility source-term characterization methodology founded on a facility-by-facility baselining of relevant radiological source terms based on a review of "existing waste certification or process stream analysis data," coupled with alternative means such as isotopic workplace air and contamination sampling (WSRC, 1999a, p. 2). Previous guidance, including various iterations of the 5Q1.1 manual during the 1990s, had included earlier guidance that was founded on facility source terms identified from "contamination survey records, safety analysis reports (SARs), technical reports, the open literature, personal interviews, etc." (WSRC, 1997, p. 3; similar statements in WSRC, 1990b, 1992, 1993).

The development of more objective, analysis-based guidance was prompted, in part, by a 1990 finding by the DOE Tiger Team that WSRC's internal dosimetry program did not comply with

DOE Order 5480.11 because "Radiological areas have not been sufficiently characterized to provide a technical basis for the assignment of bioassay sample types and frequencies" (DOE, 1990, p. 4-193). In response, WSRC noted that its approach was based on "years of experience [and an] awareness of what has constituted good practice in the past, common sense, and conservative assumptions for determining employee doses" (WSRC, 1990, PDF p. 432). Nonetheless, the WSRC corrective action plan called for "the radionuclide materials at each area on the site [to be] characterized" and for the development of the internal dosimetry technical basis manual (5Q1.1.) that was initially issued in 1992 (WSRC, 1990a, PDF p. 432). The in vitro bioassay types and frequencies table, themselves, remained essentially the same, as noted by NIOSH: "although the codes in the table were changed from those in DPSOL 193-211, the urine bioassay types were the same: plutonium, strontium, tritium, uranium, EU, and Am/Cm/Cf" (NIOSH, 2019b, p. 19).[4]

Despite this additional guidance following the Tiger Team finding, the WSRC (1999a) guidance was found necessary "in response to a concern over prescribing the correct urine bioassay sampling program[s] on radiological work permits" (WSRC, 1998b, p. 1). For example, for Building 773-A (encompassing the Savannah River Technology Center), it was observed:

> Additionally, certain facilities such as the Savannah River Technology Center (SRTC) and the solid waste disposal facilities handle a wide array of radioactive materials, some of which may not be encountered in the typical radiological work environment by workers in those areas. For facilities such as 221-FB-Line, where the source term is well defined and not subject to change, this is not a concern unless there is a major change in the facility mission. To ensure that the proper radionuclide(s) is identified for the RWP urine sampling program it may be necessary to perform a thorough characterization of the work environment. It is important also that this characterization be performed on a routine basis to stay current on the source term present. [WSRC, 1998b, p. 2]

As SC&A noted in its review of RPRT-0092, "such a routine, comprehensive characterization was not standardized practice during the DuPont era into the early WSRC era, except at specific facilities such as the Naval Fuel facility cited by DOE in its Tiger Team Assessment" (019a, p. 27).[5] The implications of not having complete or accurate radionuclides of concern SC&A, 2listed on RWPs was recognized by both DOE and WSRC during the 1990s and was the subject of iterative changes to how SRS facility source terms were identified and characterized. For those nonroutine jobs that involved "non-routine mixes or concentrations" (Findley, 1997, PDF p. 9), appropriate job-specific bioassays would not have been specified by the RWPs in question if a line manager or RCO relied upon an outdated SAR or dated process knowledge that

[4] However, there was some attention paid to updating source terms and facility applications, as noted in RPRT-0091: "The area names are not identical to the areas in the bioassay frequency table in DPSOL 193-211 but, where the areas can be matched together, there were changes in the routine bioassay types. Annual strontium sampling was added for 221-F Canyon, 221-F A-Line, and certain areas in Buildings 773-A, 772-F, and 241-84H" (NIOSH, 2019, pp. 19–20).

[5] The Naval Fuel Facility did not fall under operational management by either DuPont or WSRC. It was managed as a tenant operation by the Naval Reactors division of DOE headquarters, with its own radiological control procedures and practices.

did not reflect a new or evolving operation that would have introduced a new or unique radiological source term.

Later program developments. The formal issuance and required implementation of DOE's 10 CFR Part 835 regulation for occupational radiation protection in 1995–1996 had the effect of instilling enforceable accountability by all DOE contractors for monitoring of all potential radiation exposures of 100 millirem (mrem) or above. This was supplemented by administrative regulatory requirements governing nuclear safety program quality assurance that required managerial accountability for implementation of safety programs and procedures. There is no evidence that any further systemic program concerns were identified for SRS bioassay programs by internal or external oversight reviews following the 1998 Price-Anderson Amendments enforcement action.

The eventual implementation of and managerial accountability to the RIP upgrades to SRS radiological policies and procedures by the mid to late 1990s satisfied the bioassay program deficiencies identified by both external DOE and internal WSRC management. However, there was continued scrutiny of the SRS internal dosimetry program in the 1999–2007 period, which constitutes the balance of years in this SEC evaluation, and revisions were made.

Within WSRC, the radiological program was regularly reviewed and updated. Notably, a 2005 review of how radionuclides of interest were determined in the routine bioassay program determined that the "usefulness of waste characterization data, used extensively in the past to determine radionuclides of concern," was becoming of more limited utility given then-ongoing efforts to consolidate and reduce waste streams at SRS (WSRC, 2005, p. 8). Therefore, more professional judgement by health physicists in the characterization process was stipulated. None of these procedural updates posed a deficiency or bioassay data gap for dose reconstruction feasibility under EEOICPA.[6]

Similarly, as new issues arose, existing radiological monitoring requirements were reevaluated. An example is the question of special tritium compounds (STCs), a DOE-wide issue that involved SRS in the early 2000s and led to the addition of specific DOE guidance on internal monitoring procedures. This issue is being addressed by the SRS work group as a separate SEC matrix issue.

4.2 Realization of improvements to radiological monitoring programs, 1991–2007

As noted in section 3, newly issued or revised bioassay monitoring policies or procedures, and related programs, were not necessarily accepted and implemented fully by WSRC managers and workers in a timely manner. The embedded workplace safety culture, coupled with longstanding monitoring practices at SRS, would have made prompt sitewide changes in actual practice unlikely without accountability measures and effective self-assessments against accepted performance standards. This was acknowledged in The U.S. General Accounting Office's

[6] However, findings and recommendations for co-exposure models, neptunium, and thorium remain for work group review and closure.

(GAO's) 1990 review of that issue (related to SRS reactor restart; GAO, 1990) and reflected in the following onsite operating experience:

- the internal site FEB determination in 1994–1995 of deficiencies in bioassay sample submissions for tritium, which "prompted the site to implement a bioassay sample tracking and delinquency program for tritium bioassay in May 1996" (WSRC, 1998c)

- the WSRC self-assessment and DOE enforcement action in 1997–1998 surrounding non-submission of job-specific bioassays, which led to extensive procedural changes, including accountability and tracking measures (SC&A, 2019a)

- the FEB review and subsequent WSRC determination that concerns about nonrepresentative facility source-term characterization remained as late as 1998–1999, which led to use of a more comprehensive, analytic methodology (WSRC, 1999a)

The implementation of an RWP program, while part of the corrective actions in response to the March 1990 Tiger Team assessment, was not implemented site wide until sometime in 1991–1992, did not require bioassays for respirator use until 1992, did not specify all radionuclides of concern for job-specific bioassays until 1994, and was not supported by comprehensive, analysis-based source term characterization until 1999. While Manual 5Q1.1 requirements for these provisions were successively issued and updated beginning in 1992, administrative accountability and tracking measures to ensure that workers not covered by the routine bioassay program submitted the required job-specific bioassay samples subsequently were found to be ineffective (WSRC, 1998c).

Despite a Tiger Team finding on non-submission of bioassay samples in 1990, corrective actions to ensure adherence to job-specific bioassay requirements were only taken following a succession of noncompliance findings. These included a 1995 DOE (Savannah River Operations Office) oversight finding, a subsequent 1997 WSRC self-assessment to ascertain whether those workers required to provide job-specific bioassays actually did so, and a 1998 DOE enforcement action and WSRC corrective action program (DOE, 1998; WSRC, 1998d). As noted by WSRC, while the "expected percent participation implied by 10CFR835 and WSRC 5Q Manual is 100%," it was found that only 21 percent of sitewide workers provided the required job-specific bioassays in the second quarter of 1997 (WSRC, 1998d, p. 2). As indicated by SC&A in its various reviews of the SRS ER, the WSRC survey of job-specific bioassay completeness was limited to 1997, but the independent DOE oversight reviews of 1990 and 1995, coupled with the FEB findings in 1994–1995 (for non-submission of tritium bioassay samples), indicated that the problem persisted throughout the early 1990s under WSRC until 1998 when the bioassay collection and assurance system was overhauled.

The root problems underlying these persistent institutional deficiencies for job-specific bioassays were found by WSRC to include the following (summarized from WSRC 1998d):

- **Workers did not realize that they needed a job-specific bioassay.** "Many of the workers that missed job-specific samples were on a routine sample program but not for the isotopes for that specific job" (WSRC, 1998d, p. 3).

- **The worker was transferred before completion of the job.** "A worker may sign-out on an RWP, believing that he will be back in the near future. However, because of reassignment or other reasons, he may never return to the job" (WSRC, 1998d, p. 4). The worker may then forget or fail to submit the sample called for.

- **Workers thought they were on the correct routine bioassay program because their radiological qualifications badge (RQB) indicated the correct isotopes.** WSRC found that notations on the RQB sometimes did not match the database that generated sample requests, leading to non-submissions.

- **Bioassay requirements were not presented clearly and consistently in SRWPs and RWPs:** "the instructions in some of the SRWPs for bioassay samples were not clear. The requirements in RWPs were not presented in a consistent manner" (WSRC, 1998d, p. 4).

- **Job-specific bioassay requirements were not always adequately emphasized** in the pre-job briefings, and the workers needing job-specific samples were not always identified and documented.

Based on the significance and scope of these corrective actions, WSRC concluded in its 1998 corrective action report (WSRC, 1998d, p. 2) that:

> While it was not the function of this root cause analysis team to investigate the failure of earlier corrective actions made between March and July 1996 to the job-specific bioassay program, it was apparent that management oversight, through self-assessments and audits, to determine the effectiveness of the corrective actions was lacking. (Note: The 1996 corrective actions defined the current program). Therefore, **as an additional corrective action, the self-assessment program will be modified to include an assessment of the effectiveness of the corrective actions implemented** as a result of the root cause analysis. [Emphasis added.]

Following issuance of this WSRC corrective action report and coupled with actions taken in response to the DOE enforcement action, additional sitewide self-assessments were conducted during 1998, including a detailed examination of SRWPs requiring bioassay sampling. That followup review found multiple deficiencies in how permits prescribed bioassay sampling for radionuclides other than tritium. These included (WSRC, 1998d):

- Use of outdated permit forms that did not include a bioassay requirement block and no means to indicate which radionuclides are of concern other than reference to a procedure for facility-specific routine bioassays. As emphasized by WSRC's review of these outdated forms, "**it does not and cannot indicate the required radionuclide for a job-specific bioassay sample as this is dependent on the job being performed**" (p. 2; emphasis added).

- "It is not possible to tell by document review whether a worker meets this requirement [special precautions block indicated a bioassay code for neptunium bioassay] since **there**

is no indication on the sign-in sheet as to which facility was entered" (p. 3; emphasis added).

- "There is no consistency amongst facilities when indicating bioassay sampling related information in the special precautions section of the SRWP" (p. 4). For example, "**A job-specific bioassay sample must be submitted by workers not participating in a routine bioassay program for radionuclide(s) specified in the Bioassay Requirements section** (and nothing else)" (p. 4), meaning that while the admonition is included, no job-specific target radionuclides are specified on the permit.

- "Some facilities require bioassay sampling only when respiratory protection is worn and others require bioassay sampling when there is no requirement for respiratory protection. . . . It was determined during previous document reviews of SRWP sign-ins that **it is impossible to identify which workers should have left a bioassay sample and which did not have to in these cases because it is not apparent who wore a mask**" (p. 4; emphasis added).

- "Some facilities are not performing airborne radioactivity monitoring or setting suspension limits for radionuclides identified as requiring bioassay sampling" (p. 4).

As noted in WSRC's November 2, 1999, "Response to the Compilation of PAAA Internal Dosimetry Issues,"[7] the problem with bioassay samples not being collected and processed was "resolved initially by an elaborate administrative monitoring program to ensure job-specific sampling compliance" (WSRC, 1999b, p. 6), but WSRC determined that the final solution was the implementation of a new bioassay routine program on March 1, 1999, that "did away with the job-specific program for non-tritium samples entirely" (WSRC, 1999b, p. 6). Regarding subcontractor non-submission of bioassay samples, the same WSRC response notes that "Subcontractor workers are now being tracked administratively and can be kept from performing future site radiological work if they fail to comply with radiological requirements, including failure to provide a termination bioassay sample" (WSRC, 1999b, p. 2).

This same compilation of actions acknowledged that workers may have been enrolled in incorrect routine bioassay programs due to incorrect facility source terms being designated on RWPs. It noted that "radiological hazards are now more formally documented and both a periodic review and a method for re-evaluation [are] defined" (WSRC, 1999b, p. 6). In terms of follow up, it noted that an RCO self-assessment completed on April 30, 1999, "determined that formally documented source terms are [now] being properly used to designate bioassay requirements on RWPs" (WSRC, 1999b, p. 6).

[7] This WSRC Health Physics Technology Internal Dosimetry division reviewed a list of 31 general deficiencies provided by DOE's Office of Enforcement and Investigation as part of a 120-day suspension of enforcement actions for issues associated with DOE-wide contractor internal dosimetry evaluation programs. WSRC conducted an in-depth self-appraisal against these identified deficiencies, determined which applied to SRS, and developed corresponding corrective actions. The "Response to the Compilation of PAAA Internal Dosimetry Issues" (WSRC, 1999b) is a record of that review and actions taken.

4.3 Timetable of WSRC procedural upgrades and implementation, 1991–2007

Table 1 provides a chronology of changes to policies and procedures governing SRS bioassay monitoring in the 1989–1999 period, coupled with available assessments of program implementation and manifest bioassay data availability and completeness. This is based on the preceding history of WSRC and DOE actions in the 1990s and SC&A's and NIOSH's various assessments of bioassay data completeness for nonroutine, job-specific bioassays.

Table 1. Chronology of changes to policies and procedures and RWP bioassay data evaluation

Year	**RPRT-0092 RWP bioassay data characterization ***	**Programmatic**
1989	No RWPs available for analysis	• **April 1:** WSRC assumes SRS operations contract.
1990	Only 1 RWP available for analysis with no bioassay requirements or bioassay located for single worker involved	• **June 1:** DOE Tiger Team compliance assessment. • **September:** WSRC corrective action plan (for Tiger Team findings).
1991	RWP specifies bioassay: 3% Direct monitoring: 72% Effective monitoring: 88%	NA
1992	RWP specifies bioassay: 0% Direct monitoring: 91% Effective monitoring: 96%	• **Manual 5Q1.1, procedure 506 (rev. 0):** updated procedures for bioassay monitoring; JSB required w/ respirators.
1993	RWP specifies bioassay: 3% Direct monitoring: 70% Effective monitoring: 83%	NA
1994	RWP specifies bioassay: 63% Direct monitoring: 73% Effective monitoring: 90%	• **Target radionuclides** listed on RWPs. • **July:** SRS Facility Evaluation Board: inadequate submission of tritium bioassays.
1995	RWP specifies bioassay: 85% Direct monitoring: 68% Effective monitoring: 83%	• **February & March:** SRS Facility Evaluation Board: Inadequacies in specifying bioassay sampling requirements on RWPs. • **DOE-SR oversight:** inadequate submission of JSB.
1996	RWP specifies bioassay: 85% Direct monitoring: 75% Effective monitoring: 83%	• **May:** WSRC initiates sample tracking, delinquency followup for tritium bioassays.

Year	**RPRT-0092 RWP bioassay data characterization ***	**Programmatic**
1997	RWP specifies bioassay: 94% Direct monitoring: 95% Effective monitoring: 98%	• **WSRC self-assessment:** 79% Q2 JSB not submitted. • **100% resampling** of missing JSB show no detectable intakes. • **December:** Corrective action report issued for JSB program deficiencies.
1998	RWP specifies bioassay: 72% Direct monitoring: 80% Effective monitoring: 96%	• **January:** WSRC corrective plan w/ 11 actions to upgrade JSB program; actions completed by March 30, 1998. • **August:** 5Q1.1 (504) link between routine sampling scheduling and frequency, and RWP program eliminated – not appropriate. • **SRS Facility Evaluation Board:** source-term characterization in support of RWPs inadequate. • **September:** DOE/HQ enforcement action for inadequate submission of JSB.
1999	Outside scope of RPRT-0092 evaluation	• **March:** WSRC implements new routine bioassay program; no JSB for non-tritium samples. WSRC responses and corrective actions to SRS independent self-assessment of internal dosimetry program (including accountable termination program for subs). • **New facility source term characterization methodology** for RWPs implemented.

* Monitoring percentages reflect SC&A analysis considering all assumed or required radionuclides for RWP.

As the timeline in table 1 illustrates, WSRC developed a corrective action plan in response to the DOE Tiger Team assessment in September 1990 and conducted its own reviews, which led to the development of the RIP by late 1990. That plan included the issuance of what became the 5Q1.1 manual for internal dosimetry, which defined updated procedures for RWPs, source-term characterization, and termination bioassays, among other monitoring requirements. The initial version of 5Q1.1 was issued in 1992, followed by successive revisions, which included target radionuclides on RWPs in 1994 and additional guidance on when and how to use job-specific bioassays. These changes are manifest by the inclusion of specific radionuclide source terms on RWPs reviewed by SC&A in the 1994–1995 timeframe (refer to figure 1 and table 2). However, the problem of non-submission of bioassays identified by DOE in the 1990 Tiger Team assessment persisted at SRS, as determined by internal FEB findings for incomplete tritium bioassay submissions in 1994–1995 and for non-tritium bioassays in DOE's oversight findings in 1995 and WSRC's self-assessment in 1997.

Likewise, while WSRC committed to addressing DOE's finding of deficient facility source-term characterization to support RWPs, it was not until internal FEB findings in 1998 of continuing

reliance on longstanding and outdated SRS practices (reliance on SARs, facility experience, and expertise, etc.) that WSRC took concerted action to move to a sitewide comprehensive, analysis-based approach in 1999 to ensure that appropriate radionuclide source terms were reflected on RWPs and SRWPs according to operational presence and exposure potential.

For the time period 1999–2007, following WSRC's action to revise the sitewide in vitro internal bioassay monitoring (effective March 1, 1999) and revise specification of urine bioassay requirements on RFWPs (March 10, 1999), several SRS internal dosimetry issues arose, as discussed in the next two paragraphs.

Special tritium compounds (STCs) (also termed stable metal tritides) became a DOE-wide concern in the early 2000s and were recognized as an SRS concern as early as 2002, when WSRC initiated a sitewide survey of STCs, described existing sources at SRS, and outlined what radiological controls and monitoring would be required (WSRC, 2002). In particular, it became understood that routine bioassay monitoring may not detect the more insoluble STCs at the 100-mrem threshold defined in 10 CFR Part 835. This potential SEC issue was identified for SEC-00103 and addressed in NIOSH's ORAUT-RPRT-0072, revision 00, "Locations of Stable Metal Tritide Use at the Savannah River Site" (NIOSH, 2017a). While there were potential monitoring lapses before 2004, the use of personal air samplers with special filters and more specific identification of STCs and their solubilities for bioassay purposes resolved the concern going forward (Findley, 2010). As noted in SC&A's October 25, 2021, informal internal memorandum to the SRS and SEC Issues work groups, NIOSH and SC&A resolved all comments and responses, and the concern awaits work group action (SC&A, 2021).

An assessment of the Savannah River National Laboratory by the FEB in 2004 revisited the 1998 conclusion that waste characterization data ought to be the key means to determine the facility RWP bioassay requirements (WSRC, 2005). It was concluded that "the usefulness of waste characterization data, used extensively in the past to determine radionuclides of concern, is becoming more limited as Facilities consolidate and reduce the number of waste streams" (WSRC, 2005, p. 8). WSRC observed that "it is not necessary to perform an a priori determination of the radionuclides of interest for every task and worker within a Facility," and that an approach may be warranted making "use of PAS [personal air samplers], along with some prudent assumptions, [to allow] the task to be performed with no increased risk to the worker" (WSRC, 2005, p. 8). Finally, the assessment identified a need for the "radionuclides of concern [to be] determined . . . whenever possible, through the isotopic analysis of air samples within the facility" (p. 8). This program review indicates the attention that WSRC was giving, in this latter period, to operational changes at the site and the importance of keeping source term characterization in support of RWPs up to date.

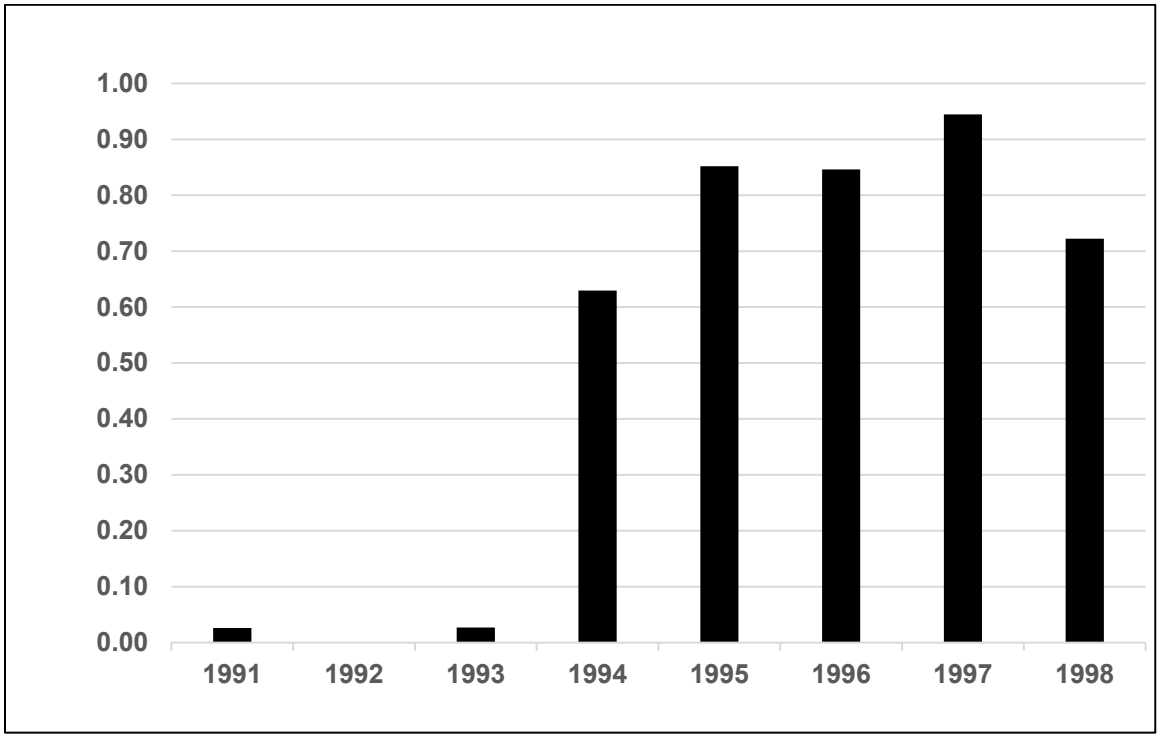
5 Review of Subcontractor Job-Specific Bioassay Completeness and Representativeness, 1991–1998

5.1 Analysis of when RWPs specified radionuclides to be bioassayed

Although corporate and policy changes were initiated in 1990, those changes did not take place immediately. It took well into the 1990s to implement changes in the field and to obtain better bioassay participation and record storage and retrieval. Some of the relevant issues and deficiencies that extended into the 1990s have been previously discussed by the SRS and SEC Issues work groups while evaluating the 1972–1990 data. If the necessary changes had been implemented relatively quickly, then there would not have been issues that were being identified and addressed in the 1990s. Examples of issues that extended into the 1990s are described in the DOE 1998 occurrence report, "Inadequate Participation in the Job-Specific Bioassay Program" (DOE, 1998b); the 1998 "Root Cause Analysis for Corrective Action Report #97-CAR-07-0001" (WSRC, 1998d); and the 1999 WSRC interoffice memorandum, "Response to the Compilation of PAAA Internal Dosimetry Issues" (WSRC, 1999b).

SC&A analyzed the data in table C-1 of RPRT-0092 to determine when RWPs began to state if a bioassay was necessary, and the types of radionuclides that should be bioassayed. SC&A sorted the data in table C-1 according to the year of the RWP (1991–1998) and determined the total number of radionuclide bioassays mandated by adding the number of bioassays specifically required by an RWP (represented by the symbol "R" in table C-1) plus the number assumed to be needed by NIOSH (represented by the symbol "A" in table C-1). The number (R) of bioassays specifically stated on the RWP was then divided by the total number (R + A) of mandated bioassays to obtain the fraction of bioassays mandated in RPRP-0092 that were specifically required on the RWPs. The results for 1991–1998 are shown in figure 1.

Figure 1. Fraction of total mandated bioassays that were listed on the RWP versus year



The analysis was performed for each of the major radionuclides commonly bioassayed for at SRS for the years 1991–1998. The results are summarized in table 2.

Table 2. Percent of RWP-specified radionuclide bioassays compared to total number of mandated radionuclide bioassays as listed in RPRT-0092, table C-1

Year	Percent of Pu bios required by RWPs	Total of RWP plus assumed Pu bios	Percent of Sr/FPs bios required by RWPs	Total of RWP plus assumed Sr/FPs bios	Percent of Am bios required by RWPs	Total of RWP plus assumed Am bios	Percent of U bios required by RWPs	Total of RWP plus assumed U bios	Percent of Np bios required by RWPs	Total of RWP plus assumed Np bios
1991	0%	16	0%	13	0%	4	25%	4	0%	1
1992	0%	23	0%	9	0%	12	0%	20	0%	2
1993	4%	27	0%	12	0%	13	9%	11	0%	11
1994	78%	32	72%	25	33%	9	33%	15	NA	0
1995	100%	15	100%	5	0%	2	100%	2	33%	3
1996	100%	7	100%	3	0%	2	NA	0	100%	1
1997	100%	9	100%	8	0%	1	NA	0	NA	0
1998	80%	10	71%	7	0%	1	NA	0	NA	0

Note: bios = bioassays; Pu = plutonium; Sr/FPs = strontium/fission products; Am = americium; U = uranium; Np = neptunium; NA = not applicable.

The results in figure 1 and table 2 indicate that RWPs began to specify that a bioassay was required for certain radionuclides in the mid-1990s (1994 to 1995).

5.2 Requiring only at least one bioassay versus requiring all mandated bioassays

When SC&A compared data in RPRT-0092, table 4-1 (sCTWs with at least one bioassay for any radionuclide, 1990–1998), to data obtained when considering all mandated radionuclides for an RWP (with a 2-year time limit on chest counts), it was found that the results adjust downward to lower percentages. For the period 1991–1998 for table 4-1 and table 6-4 (rates of monitoring sCTWs for at least one radionuclide, 1981–1988), the average percentage with at least one bioassay directly monitored to satisfy an RWP was 96 percent, while SC&A's recalculated average percentage with bioassays for all mandated radionuclides directly monitored as specified for an RWP was 77 percent. The values from table 4-1 and table 6-4 of the average percentage of sCTWs effectively monitored for at least one bioassay for an RWP was 98 percent, while SC&A's recalculated average percentage effectively monitored for all mandated radionuclides to satisfy an RWP was 89 percent. Table 3 summarizes the results of NIOSH's analysis in RPRT-0092 and SC&A's analysis for direct monitoring; table 4 summarizes effective monitoring, which included bioassays for plutonium (Pu), strontium/fission products (Sr/FPs), uranium (U), americium (Am), and neptunium (Np), as mandated for an RWP, for 1991–1998.

Table 3. Breakdown by year of using all mandated radionuclides and using only at least one radionuclide for sCTWs directly monitored 1991–1998

Year	Total number of sCTW-RWP matches requiring bioassays	SC&A percent directly monitored for all mandated radionuclides	RPRT-0092 table 4-1 percent directly monitored for at least one radionuclide
1991	81	72%	99%
1992	106	91%	97%
1993	173	70%	97%
1994	140	73%	94%
1995	57	68%	95%
1996	24	75%	83%
1997	55	95%	98%
1998	25	80%	92%
1991–1994	**500**	**75%**	**97%**
1995–1998	**161**	**80%**	**94%**
All years	**661**	**77%**	**96%**

Table 4. Breakdown by year of using all mandated radionuclides and using only at least radionuclide for sCTWs effectively monitored 1991–1998

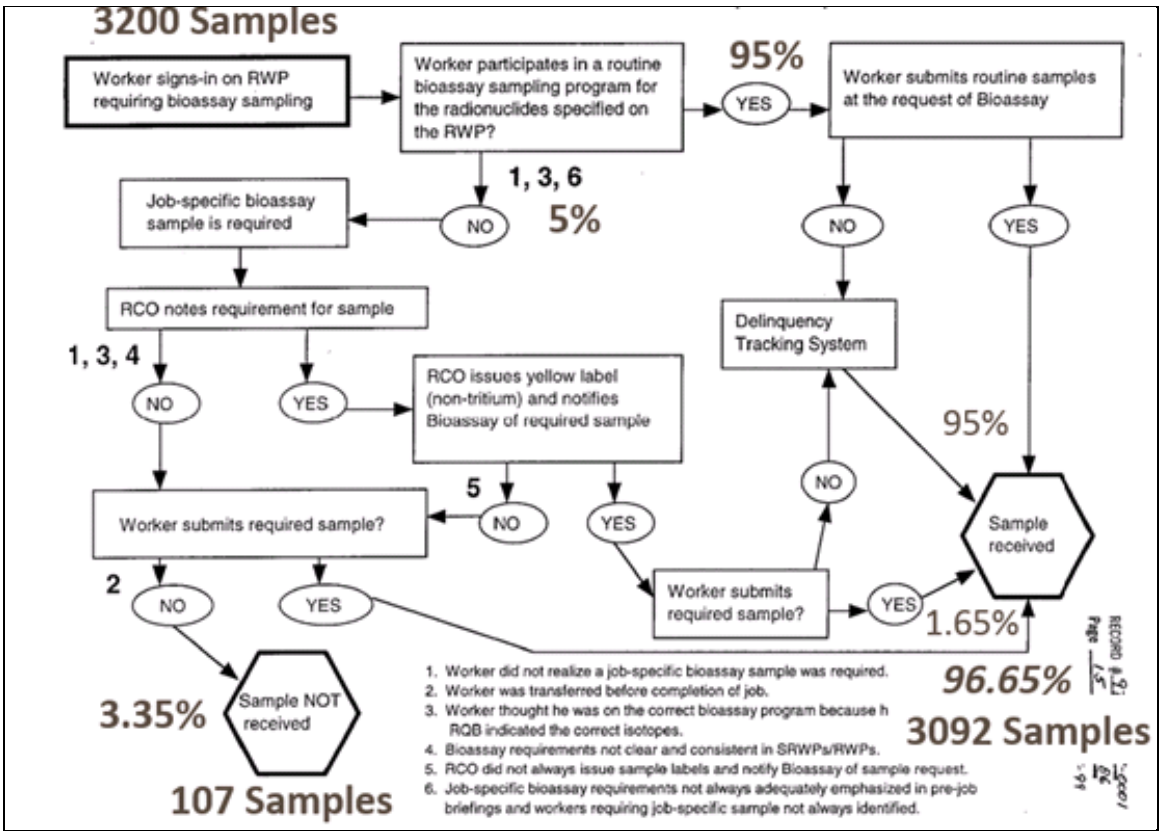
Year	Total number of sCTW matches requiring bioassays	SC&A percent effectively monitored for all mandated radionuclides	RPRT-0092 table 4-1 percent effectively monitored for at least one radionuclide
1991	81	88%	100%
1992	106	96%	100%
1993	173	83%	99%
1994	140	90%	96%
1995	57	83%	100%
1996	24	83%	83%
1997	55	98%	100%
1998	25	96%	100%
1991–1994	**500**	**89%**	**98%**
1995–1998	**161**	**90%**	**98%**
All years	**661**	**89%**	**98%**

The results of using NIOSH's criteria that only one bioassay needed to be monitored to fulfill the RWP monitoring requirements as opposed to requiring that all mandated radionuclides for an RWP be monitored to fulfill RWP requirements are sometimes misleading because they do not incorporate the need for the sCTW, or the co-exposure worker, to be monitored for all mandated radionuclides, with the chest count limited to 2 years. The details of this issue were presented in section 6.2.2 of SC&A's 2019 review of RPRT-0092 (SC&A, 2019a). Additionally, the merits of using co-exposure data to add to the percentage of sCTW monitored is debatable; this issue was presented in section 6.3 of SC&A's 2019 review of RPRT-0092 (SC&A, 2019a).

5.3 RPRT-0092 data versus 1997 SRS self-assessment

A more significant issue is that the data used in RPRT-0092 appear to have failed to identify the missed job-specific bioassays as outlined in figure 4-4, page 39, of RPRT-0092 (NIOSH, 2019a; reproduced here as figure 2), which was taken from WSRC (1998d). The flowchart is the expected process; the large numbers represent actual first four months of 1997 participation as analyzed in May 1997 (NIOSH, 2019a, p. 38).

Figure 2. Figure 4-4 from RPRT-0092: attachment 2 to root cause analysis corrective action report



Source: NIOSH (2019a), figure 4-4, "Attachment 2 to Root Cause Analysis Corrective Action Report ([WSRC, 1998d], p. 23). The flowchart is the expected process; the large numbers represent actual May 1997 participation."

SC&A analyzed the data in RPRT-0092 to determine the percentage of sCTWs bioassayed for the total number of mandated bioassays (R + A) for an RWP when all mandated radionuclides are needed for the sCTW to be considered monitored. The results for both directly and effectively monitored sCTWs are shown in figure 3. The percent values are similar to those in tables 10 and 12 of SC&A's RPRT-0092 review (SC&A, 2019a).

Figure 3. Percent of directly and effectively monitored sCTWs per RWP-mandated bioassays (R + A)

However, the mostly routine bioassay data tend to overshadow the missed sCTW job-specific bioassays, such as those in the set of 107 missed bioassays during the first four months of 1997, as referred to in figure 4-4 and page 38 of RPRT-0092. The much lower number of job-specific bioassays would not have the potential to provide a significant impact on the overall percent monitored.

5.4 Analysis of compliance as a function of building for 1991–1998

SC&A analyzed compliance of mandated bioassays for sCTWs as a function of the buildings specified on RWPs for the period 1991–1998 to determine if there appeared to be an inflection point that might demonstrate an increase in bioassay compliance. SC&A performed this analysis on an annual basis for each of the five major radionuclides bioassayed for at SRS—plutonium, uranium, strontium/fission products, americium, and neptunium—for all buildings listed on RWPs for the period 1991–1998, for both direct monitoring and effective monitoring. Tables 5–9 summarize the results for directly monitored sCTWs. Results with less than 80 percent compliance are indicated in tables 5–9 by a table note and bold italic formatting. SC&A's selection of the compliance value less of than 80 percent was arbitrary, but it was a reasonable value below which the rate of compliance certainly would be questionable.

Table 5. Percent of directly bioassayed sCTWs working on RWPs for plutonium versus area and year

Area and building	Total number of Pu mandated bioassays [a]	1991	1992	1993	1994	1995	1996	1997	1998
A-773	112	89%	100%	86%	100%	NA	NA	NA	NA
E-230	4	NA	NA	NA	100%	NA	NA	NA	NA
E-643	19	NA	NA	100%	***40%*** [b]	NA	NA	100%	NA
F-211	1	NA	NA	NA	NA	NA	NA	NA	100%
F-221	33	NA	100%	NA	NA	***60%*** [b]	NA	100%	***56%*** [b]
F-235	24	100%	NA	***73%*** [b]	NA	100%	NA	NA	NA
F-241	75	***78%*** [b]	NA	80%	NA	NA	100%	97%	89%
F-247	11	100%	NA	***78%*** [b]	NA	NA	NA	NA	NA
F-281	3	NA	NA	NA	100%	NA	NA	NA	NA
F-292	5	NA	NA	NA	NA	100%	NA	NA	NA
F-294	6	NA	NA	NA	NA	83%	NA	NA	NA
F-772	23	NA	100%	NA	***55%*** [b]	NA	NA	NA	NA
F-FA-Line	2	NA	NA	NA	NA	100%	NA	NA	NA
F-FB-Line	11	100%	100%	NA	NA	NA	NA	100%	100%
F-FTF	1	NA	NA	NA	NA	NA	NA	NA	100%
H-0BL	65	NA	100%	94%	NA	NA	NA	NA	NA
H-211	4	NA	100%	NA	NA	NA	NA	NA	100%
H-221	75	NA	93%	92%	100%	93%	***60%*** [b]	NA	NA
H-241	42	96%	89%	NA	NA	NA	NA	NA	NA
H-242	14	100%	NA	NA	NA	NA	NA	NA	NA
H-261	2	NA	NA	NA	NA	NA	NA	100%	NA
H-281	2	NA	NA	NA	100%	NA	NA	NA	NA
H-292	11	NA	100%	NA	NA	NA	NA	NA	NA
H-299	9	100%	NA	NA	NA	NA	NA	NA	NA
H-HBL	2	NA	NA	NA	NA	***50%*** [b]	NA	NA	NA
H-HCMA	4	NA	NA	100%	NA	NA	NA	NA	NA
Outside	4	NA	NA	***75%*** [b]	NA	NA	NA	NA	NA
Z-210	5	NA	NA	NA	***40%*** [b]	NA	NA	NA	NA
Z-451	59	NA	NA	NA	***61%*** [b]	NA	NA	NA	NA
Z-704	15	NA	NA	NA	***60%*** [b]	NA	NA	NA	NA

[a] Total number of mandated bioassays are those specified on RWP plus assumed bioassays for the RWP.

[b] Results with <80% compliance.

Note: NA = No RWPs for that year for that building. Percentage values are percent of sCTWs directly bioassayed as mandated for RWPs, with chest counts within 2 years.

Table 6. Percent of directly bioassayed sCTWs on RWPs for strontium/fission products versus area and year

Area and building	Total number of Sr/FPs mandated bioassays	1991	1992	1993	1994	1995	1996	1997	1998
A 773	112	100%	100%	100%	100%	NA	NA	NA	NA
E 230	4	NA	NA	NA	100%	NA	NA	NA	NA
E 643	19	NA	NA	100%	***60%*** [a]	NA	NA	100%	NA
F 221	24	NA	NA	NA	NA	80%	NA	100%	***78%*** [a]
F 241	76	100%	NA	100%	NA	NA	86%	92%	100%
F 247	4	100%	NA	100%	NA	NA	NA	NA	NA
F 281	3	NA	NA	NA	100%	NA	NA	NA	NA
F 292	5	NA	NA	NA	NA	100%	NA	NA	NA
F 294	6	NA	NA	NA	NA	100%	NA	NA	NA
F 772	16	NA	92%	NA	100%	NA	NA	NA	NA
F FA-Line	2	NA	NA	NA	NA	100%	NA	NA	NA
F FTF	1	NA	NA	NA	NA	NA	NA	NA	100%
F outside	4	NA	NA	100%	NA	NA	NA	NA	NA
H 211	1	NA	NA	NA	NA	NA	NA	NA	100%
H 221	4	NA	NA	NA	NA	100%	NA	NA	NA
H 241	42	96%	95%	NA	NA	NA	NA	NA	NA
H 242	9	100%	NA	NA	NA	NA	NA	NA	NA
H 261	2	NA	NA	NA	NA	NA	NA	100%	NA
H 299	9	100%	NA	NA	NA	NA	NA	NA	NA
H HCMA	4	NA	NA	100%	NA	NA	NA	NA	NA
Z 210	5	NA	NA	NA	100%	NA	NA	NA	NA
Z 451	59	NA	NA	NA	100%	NA	NA	NA	NA
Z 704	15	NA	NA	NA	100%	NA	NA	NA	NA

[a] Results with <80% compliance.

Table 7. Percent of directly bioassayed sCTWs working on RWPs for uranium versus area and year

Area and building	Total number of U mandated bioassays	1991	1992	1993	1994	1995	1996	1997	1998
A-773	98	***50%*** [a]	100%	82%	95%	NA	NA	NA	NA
F-221	6	NA	83%	NA	NA	NA	NA	NA	NA
F-247	11	***50%*** [a]	NA	89%	NA	NA	NA	NA	NA
F-281	3	NA	NA	NA	100%	NA	NA	NA	NA
F-772	16	NA	100%	NA	100%	NA	NA	NA	NA
H-211	3	NA	100%	NA	NA	NA	NA	NA	NA
H-221	45	NA	93%	83%	90%	100%	NA	NA	NA
H-281	2	NA	NA	NA	100%	NA	NA	NA	NA
H-299	9	***56%*** [a]	NA	NA	NA	NA	NA	NA	NA
H-HCMA	4	NA	NA	100%	NA	NA	NA	NA	NA
H-OBL	9	NA	100%	NA	NA	NA	NA	NA	NA
M-313	3	NA	100%	NA	NA	NA	NA	NA	NA
M-316	2	NA	100%	NA	NA	NA	NA	NA	NA
M-321	13	NA	92%	NA	NA	NA	NA	NA	NA

[a] Results with <80% compliance.

Table 8. Percent of directly bioassayed sCTWs working on RWPs for americium versus area and year

Area and building	Total number of Am mandated bioassays	1991	1992	1993	1994	1995	1996	1997	1998
A-773	13	NA	NA	NA	92%	NA	NA	NA	NA
F-247	7	***0%*** [a]	NA	***20%*** [a]	NA	NA	NA	NA	NA
F-772	4	NA	100%	NA	NA	NA	NA	NA	NA
H-211	4	NA	100%	NA	NA	NA	NA	NA	100%
H-221	49	NA	***73%*** [a]	***67%*** [a]	90%	***33%*** [a]	100%	NA	NA
H-242	9	***22%*** [a]	NA	NA	NA	NA	NA	NA	NA
H-261	2	NA	NA	NA	NA	NA	NA	100%	NA
H-281	2	NA	NA	NA	100%	NA	NA	NA	NA
H-292	11	NA	100%	NA	NA	NA	NA	NA	NA
H-299	9	***44%*** [a]	NA	NA	NA	NA	NA	NA	NA
H-HCMA	4	NA	NA	***50%*** [a]	NA	NA	NA	NA	NA
H-OBL	65	NA	92%	***65%*** [a]	NA	NA	NA	NA	NA

[a] Results with <80% compliance.

Table 9. Percent of directly bioassayed sCTWs working on RWPs for neptunium versus area and year

Area and building	Total number of Np mandated bioassays	1991	1992	1993	1994	1995	1996	1997	1998
F-235	20	***50%*** [a]	NA	***45%*** [a]	NA	***33%*** [a]	NA	NA	NA
H-HBL	2	NA	NA	NA	NA	***0%*** [a]	NA	NA	NA
H-OBL	65	NA	100%	***71%*** [a]	NA	NA	NA	NA	NA

[a] Results with <80% compliance.

The percentage values in tables 5–9 do not indicate an obvious change in bioassay compliance during the period 1991–1998 for the five radionuclides. However, for some of the radionuclides there was an insufficient number of RWPs during the 1995–1998 period to provide statistically significant results.

However, table 8 and table 9 do indicate significant noncompliance issues for americium and neptunium for the period 1991–1995. The same analysis method was conducted for effectively monitored sCTW on RWPs for the period 1991–1998 with similar results as for directly monitored sCTWs, with an equal or greater percentage of sCTW effectively monitored because co-exposure bioassays were also included.

5.5 Analysis of noncompliance for 1991–1998

SC&A further analyzed the results in terms of noncompliance as a function of radionuclide and year. For the purpose of this exercise, SC&A selected <80 percent as an arbitrary threshold for direct bioassay monitoring for an area or building, below which compliance would certainly be questionable. SC&A divided the results into two periods, 1991–1994 and 1995–1998, to see if there was any obvious step function that would indicate a greater compliance rate after 1994 when RWPs began to be more prescriptive. However, there does not appear to be a defining inflection point. Figures 4 and 5 summarized the results for sCTWs directly monitored. In these two figures, a high fraction of missed bioassay results means poor compliance. The results were mixed. For example, bioassay noncompliance was greater for plutonium, uranium, and americium for 1991–1994 (taller hashed bars) compared to 1995–1998 (shorter black bars) as shown in figure 4, but Sr/FPs and neptunium bioassay noncompliance was greater for 1995–1998 (taller black bars) compared to 1991–1994 (lower hashed bars) as shown in figure 5. However, there were only three RWPs with 11 workers for 1995 for neptunium. Americium and neptunium had a greater amount of noncompliance (ranging from 20 to 100 precent) compared to plutonium, Sr/FPs, and uranium (noncompliance ranged from zero to 24 precent), perhaps because plutonium, Sr/FPs, and uranium were more likely to be covered by routine bioassays whereas americium and neptunium radionuclides were not as common (and more likely to be on job-specific bioassays). As mentioned previously, for some radionuclides there was an insufficient number of RWPs in the 1995–1998 period to provide statistically significant results.

Figure 4. Directly bioassayed radionuclides with 1991–1994 noncompliance fraction greater than 1995–1998 noncompliance fraction

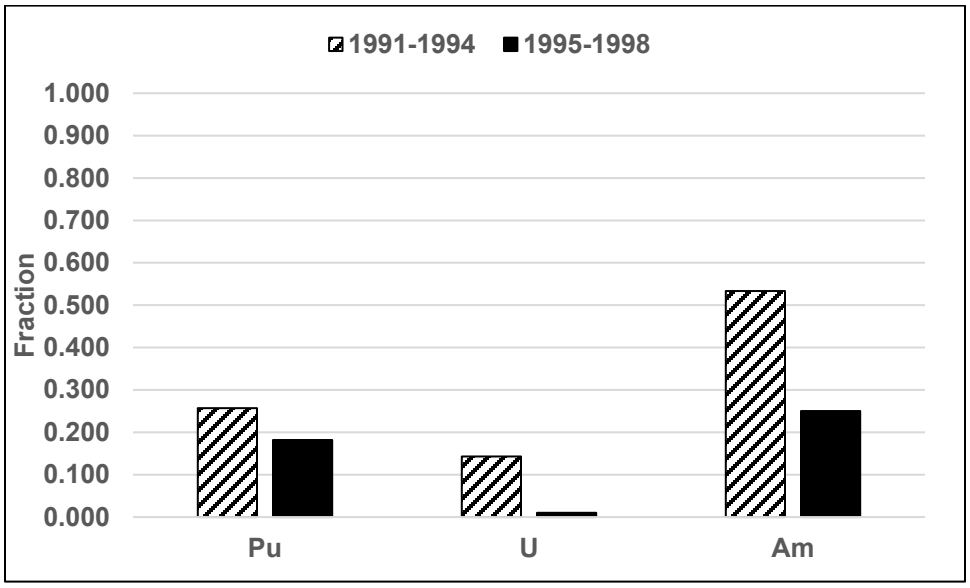


Figure 5. Directly bioassayed radionuclides with 1991–1994 noncompliance fraction less than 1995–1998 noncompliance fraction

The same analysis method was conducted for effectively monitored sCTWs on RWPs for the period 1991–1998, with similar results as for directly monitored sCTWs, with equal or less noncompliance values for sCTW bioassays because co-exposure bioassays were also included.

6 Review and Overview of SEC-Related Issues, 1972–2007

On behalf of the SRS work group, SC&A has maintained an updated SEC issues matrix, starting in September 2009, that compiles all identified exposure potential issues at SRS based on the work group's review of petition SEC-00103. The original 2009 matrix (SC&A, 2009) was based on issues that were unresolved from the SC&A review of the SRS site profile and SC&A's preliminary review of NIOSH's ER (NIOSH, 2008). The 2009 matrix listed 25 issues of SEC relevance.

Until 2022, the most recent update to the SEC issues matrix was issued in February 2014 (SC&A, 2014a) following the designation of an SEC class for all SRS employees for 1953–1972. This designation rendered moot some SEC issues, while others needed additional research to address questions related to latter time periods, including those for CTWs, nuclide-specific issues (e.g., neptunium, special tritium compounds, and thorium), and co-exposure modeling. For this current review, SC&A reviewed the 2014 matrix to confirm any outstanding issues for which documented resolution is not apparent.

Of the 26 SEC-relevant issues listed in the 2014 matrix, three issues lacked a documented resolution: issue 3 for "Recycled Uranium," issue 22 for "Badges not capturing dose," and issue 26 for "additional worker and worker representative issues."

The original recycled uranium (RU) issue, which was identified in SC&A's 2005 site profile review (SC&A, 2005), found that a timeline for RU operations had not been issued and it was not clear when and how RU (with trace radiological contaminants) may have been handled at SRS. NIOSH issued trace contaminant data for RU in 2010 (NIOSH, 2010), and SC&A responded with a memorandum about remaining RU issues in 2014 (SC&A, 2014b). While there is no confirmation of an outstanding SEC issue, no final resolution was apparent in the work group records on this matter.

For issue 22 (and subsumed issue 23), SC&A had found that worker interviews indicated that some workers kept their badges out of higher radiation areas in order to not exceed dose limits (SC&A, 2011) and that badge dose reading may have been under-recorded or not recorded. NIOSH was to review SC&A's report of these worker interviews and provide a response.

For issue 26, SC&A had compiled and categorized a number of worker and petitioner comments about specific workplace issues for which a specific NIOSH response has not been received to date. However, as noted in SC&A's recently updated matrix (SC&A, 2022), a number of the comments are addressed in existing SEC issues reviewed by the work group and NIOSH.

A number of other SEC-relevant issues from the 2014 matrix have either been closed, resolved, subsumed under other issues, or superseded by the 2011 Board action to recommend an SEC for 1953–1972 (issues 1, 8, 12, 15, 16, 17, 18, 19, 21, 23, 24, and 25). Still others are being addressed by the development of co-exposure models under ORAUT-OTIB-0081, "Internal Dosimetry Co-Exposure Data for the Savannah River Site": issue 2 for thorium via ORAUT-RPRT-0070 (NIOSH, 2017c) and ORAUT-RPRT-0081 (NIOSH, 2017d); issue 4 for trivalent actinides and thorium; issues 6 and 7 for fission and activation products; issue 9 for tritium; and issue 13 for comparing intakes for construction workers versus non-construction workers. Issue 5

for Np-237 has been addressed by NIOSH in ORAUT-RPRT-0065 (NIOSH, 2016a), ORAUT-RPRT-0077 (NIOSH, 2016b), and ORAUT-RPRT-0080 (NIOSH, 2017b) and is being handled by the work group as an ongoing issue. Issue 10 for special tritium compounds, which are being addressed as "Metal Hydrides" in ORAUT-RPRT-0072 (NIOSH, 2017a), is also ongoing. Issue 11 (exotic radionuclides), issue 14 (special exposure conditions), and issue 20 (tank farm geometry) have reached the resolution stage and are ready for work group review for closure.

Other than the three specific outstanding items—issues 3, 22, and 26, none of which have been judged SEC significant to date—SC&A has determined that the relevant SEC issues have flowed down to and have been included in subsequent priority action lists presented by NIOSH to the work group. Their status is summarized in SC&A's informal internal update of SEC-00103 issues status in October 2021 (SC&A, 2021).

Given how long ago this 2014 issues matrix was last updated and the challenge faced by SC&A in reconstructing several status items, SC&A recently updated this matrix and provided it to the work group and NIOSH on March 11, 2022, for review and use in upcoming discussions (SC&A, 2022). This matrix is attached to this report as attachment A for convenience. An updated version of SC&A's internal October 2021 SEC issues status update is provided as attachment B.[8]

No other potential SEC issues have been identified by SC&A for the 1972–2007 period, with the possible exception of the scope of CTWs that can and should be addressed by the aforementioned co-exposure models. The recently designated SEC class identified sCTWs as the worker cohort whose exposure potential would likely be higher than other CTWs due to their nonroutine work assignments involving "short-term high-exposure work tasks," with an attendant "lack of assurance provided their bioassay monitoring, and identified gaps in the permit-driven job-specific monitoring program" at SRS for at least 1972–1990 (ABRWH 2021, p. 1, attachment p. 2). However, it is evident that other CTWs, as a whole, performed similar RWP tasks, sometimes side-by-side with sCTWs having similar exposure potentials, although the former likely would have been less transitory in their work tasking. Programmatically, the lack of assurance provided their job-specific bioassay monitoring would have impacted CTWs on job plans and RWPs, the same as for sCTWs. Currently, the distinction being made between the two worker categories stems from a subjective judgment of the higher exposure potential of sCTWs, an issue raised early and extensively analyzed by both NIOSH and SC&A during the prior SEC evaluation review.[9] That assessment needs to be balanced against data incompleteness for both cohorts stemming from job-specific bioassays not necessarily being performed reliably and adequately for required radionuclides. In the context of bioassay data completeness and

[8] Note that the version in attachment B has been modified slightly for accuracy based on a teleconference between SC&A and NIOSH in January 2022; the recent changes are noted in the attachment.

[9] This analysis was part of the work group's review of stratification for co-exposure model development: beginning with NIOSH's 2017 presentation comparing DuPont CTWs with DuPont sCTWs for plutonium analysis, 1956–1988, as a means to compare 95th percentile urinary excretion rates in support of sCTWs being included in the same cohort as CTWs, followed by a NIOSH white paper (NIOSH, 2019c), an SC&A response (SC&A, 2019b), and a NIOSH response (NIOSH, 2020a). Based on its analyses, NIOSH's position is "that the exposure conditions and the potential for intakes were similar among all CTWs (prime and subcontractor), therefore a combined strata is appropriate" (NIOSH, 2020a, slide 21).

representativeness under DCAS-IG-006, revision 00, “Criteria for the Evaluation and Use of Co-exposure Datasets” (NIOSH, 2020b), the distinction between sCTWs and CTWs on permit-directed, job-specific bioassays bears further work group deliberation in the context of this review.

7 Summary Conclusions

Based on the reviews discussed in this report, SC&A has the following conclusions:

1. **Sampling premise is not sufficiently grounded in historical SRS practices.** Measured against the review criteria used by SC&A's review of RPRT-0092, the sampling premise is not sufficiently grounded in actual WSRC policies, procedures, and practices within the time period 1991–1998. While RWPs were implemented by procedure in 1992 (and were being rolled out by WSRC before then), along with more specific target radionuclides listed on RWPs, SC&A finds that demonstrable implementation of these requirements was not apparent in the workplace until 1994–1995, as evidenced by figure 1 and table 2. Figure 1 shows that the percentage of required bioassays listed on the RWPs rose from very few (less than 5 percent) in 1991–1993 to over 60 percent in 1994 and over 80 percent in 1995. Correspondingly, table 2 shows that the percent of RWP-specified radionuclide bioassays compared to total bioassays listed in table C-1 of RPRT-0092 rose for plutonium from zero percent in 1991 to 78 percent and 100 percent in 1994 and 1995, respectively. While these results could also imply that prescheduled bioassays were actually performed in place of job-specific bioassays but simply not cited on the RWPs, they also indicate that RWPs may have lacked adequate documentation and completeness. (Table 2 also notes that for other radionuclides of concern—americium, uranium, and neptunium—the percent of radionuclide-specific bioassays required by RWPs ranged from zero to 25 percent for 1991–1993). While RPRT-0092 finds a relatively high level of direct and effective matches for sCTWs listed on RWPs, this may not be a valid comparison for the sake of bioassay data representation, given the nascent state of RWP program implementation that may bias the percentage of sCTWs bioassayed higher for the already prescheduled radionuclides of concern (e.g., plutonium, americium, and fission products).

2. **Results for direct and effective monitoring may be overstated.** SC&A continues to conclude that, as with the earlier SEC period of 1972–1990, NIOSH did not address all of the radionuclides listed in the RWPs when determining data completeness for job-specific bioassay monitoring, and, therefore, the percentage of matching results for direct and effective monitoring appear to be overstated in the RPRT-0092 summary in section 6.3. This is most relevant for the 1991–1994 period, when (as noted in conclusion 1) many exposure-relevant radionuclides of concern were not yet included in RWPs and inaccurate facility source term assumptions may have been made, as noted by DOE in 1990 (DOE, 1990) and by WSRC in 1999 (WSRC, 1999a). While RPRT-0092 claims a relatively high percentage of both direct and effective matches between RWPs and listed sCTWs or their coworkers for at least one bioassay (averages of 96 and 98 percent, respectively), SC&A's review found these values to be lower (averages of 77 percent directly and 89 percent effectively monitored) when matched against all mandated radionuclides for RWPs. These results tend to be dampened in a sitewide comparison, given the much larger numbers of prescheduled bioassays (plutonium, Sr/FPs, uranium), but become more apparent at the facility level, as shown in tables 5, 6, and 7. For the period 1991–1994, there are facility-specific instances of significantly lower percentages of directly bioassayed sCTWs (e.g., 50 percent for uranium at A-773 and at F-247 in 1991, as shown in table 7). RWPs themselves would not necessarily have

included complete in vitro bioassay requirements until March 1999, when WSRC expanded its bioassay specifications to include facility-specific analytic characterization information (WSRC, 1999a).

3. **Generalized matching is not sufficient.** Concerning co-exposure model datasets, SC&A found in a focused review of RPRT-0092 plutonium coworker matches during the 1991–1998 WSRC period that, while nearly 96 percent of identified coworker matches involved the same RWP, inclusion of additional criteria (e.g., the same date, time, and craft) decreases this percentage significantly (down to 45 percent) (SC&A, 2019a, p. 66). Given the often nonroutine and intermittent nature of sCTW jobs under RWPs, sometimes involving unique radiological source terms, SC&A believes such matching needs to be more closely aligned with what is listed on the actual RWP. While the co-exposure implementation guide (NIOSH, 2020b) does not specify an objective measure for data completeness to support the representativeness of a co-exposure model, it does require a determination be made that "there are sufficient measurements to ensure that the data are either bounding or representative of the exposure potential for each job/exposure category at the facility" (NIOSH, 2015, p. 5). SC&A does not consider a generalized match of workers to RWP-specified, job-specific bioassays to satisfy the need to demonstrate that this data set is either bounding or representative of subcontractor exposure potential that should have been monitored by job-specific bioassay.

4. **RWP-specified, job-specific bioassay data are incomplete.** RWP-required, job-specific bioassay data should be assumed to be substantially incomplete for purposes of demonstrating monitoring data completeness and representativeness for use in a co-exposure model until the end of 1996 (a 100-percent resampling of all workers on job-specific bioassays was performed for 1997; enhanced accountability and tracking of job-specific bioassays were implemented in 1998). This is based on independent program audits that found that lapses in bioassay submission existed during the 1991–1996 timeframe, spanning from the initial 1990 Tiger Team findings about bioassay program noncompliance to the 1997–1998 WSRC actions in response to DOE field audits, internal FEB findings, and DOE headquarters enforcement action. This is consistent with SC&A's analysis in figures 4 and 5, where SC&A compared the noncompliance fraction (missed bioassay results) of directly bioassayed radionuclides (plutonium, uranium, americium, Sr/FPs neptunium), in terms of being greater or lower for the period 1991–1994, as compared with 1995–1998, respectively. These comparisons are most evocative for uranium and americium, with bioassay noncompliance being significantly higher for the earlier period. The opposite is true for neptunium and Sr/FPs, but by only a small margin over fewer data points. As expected, plutonium is essentially the same for both periods, likely due to its outsized prevalence in SRS operations and by its prescribed, prescheduled monitoring

5. **Feasibility of co-exposure model needs to balance RWP implementation with completeness of coworker data.** Given conclusion 4, it is also clear that sCTWs who were on RWPs and may not have been monitored likely worked alongside coworkers who were monitored according to the RWP requirements. If RWPs can be considered complete and adequate (because the concerns identified in conclusions 1 and 2 have been addressed) and implemented in an accountable manner with the requisite bioassays

substantially performed (per conclusion 4), SC&A would consider NIOSH's conclusion valid that the RPRT-0092 sampling review demonstrates sufficient matches (direct and effective) in the 1991–1998 period to support development of a co-exposure model for sCTWs on job-specific bioassays who lacked internal monitoring data. While job-specific bioassays and source terms may be incomplete, given the programmatic shortfalls, this is mitigated by two considerations: (1) job-specific bioassays made up only 5 percent of total bioassays by 1997[10] and (2) a full resampling of job-specific bioassay results for the second quarter of 1997 found no evidence of intakes. Accordingly, a conclusion about the feasibility of a co-exposure model for workers lacking bioassay results for nonroutine work may be reached by balancing the programmatic limitations of the RWPs and job-specific bioassays with the availability of suitable coworker bioassay data (as given in RPRT-0092).

To summarize, the issue of data completeness and representativeness in this instance are clearly a subjective measure that must weigh two things against one another: (1) programmatic evidence (i.e., the temporal nature of procedural development, implementation, and realization in light of the documented program deficiencies) and (2) the observed monitoring results for sCTWs in the available sample of RWPs (i.e., the RPRT-0092 dataset). Programmatic evidence indicates that the job-specific monitoring program and source characterization was a developing program during the 1990s and that there were documented deficiencies found by both DOE and WSRC as late as 1999 (e.g., 79 percent noncompliance in the job-specific program). For observed monitoring results, a sampling of RWPs during this same period indicates that many workers were directly monitored[11] or on the same RWP as an assumed coworker who was monitored, resulting in their being effectively monitored.[12] The majority of these monitoring results are logically a result of enrollment in the pre-scheduled, routine program and thus do not obviate the deficiencies in completeness of the job-specific monitoring program. However, it must be determined if, and when, the observed coverage of the routine monitoring program is sufficient to justify the representativeness of any subsequent co-exposure model as applied to workers who should have been covered by the deficient job-specific program.

Regarding other SEC-relevant issues for SEC-00103, SC&A has found no outstanding issues other than (1) the need to reconcile the scope of the CTW cohort that can and should be addressed by existing co-exposure models, and (2) several remaining action items for work group discussion and closure from previous issues matrices (these are listed and updated in attachments A and B).

[10] This is demonstrated by a WSRC self-assessment of internal monitoring program participation in May 1997, although this one-time sampling is not necessarily applicable to earlier years and it is evident that the numbers of subcontractors on site at SRS peaked in the early 1990s (as illustrated by, among other sources, the NOCTS dataset (NIOSH, 2019d).

[11] Seventy to 95 percent depending on the year, per SC&A's calculation of direct monitoring for all assumed/required radionuclides associated with a given RWP.

[12] Eighty-three to 99 percent depending on the year, per SC&A's calculation of effective monitoring for all assumed/required radionuclides associated with a given RWP.

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Attachment A: Issues Matrix for SRS

[This attachment reproduces a March 11, 2022, SC&A memorandum to the Savannah River Site and SEC Issues work groups, "March 2022 Update of Issues Matrix for the SRS SEC Petition and Petition Evaluation Report."]

On behalf of the Savannah River Site (SRS) work group, SC&A maintained and updated a Special Exposure Cohort (SEC) issues matrix, starting in September 2009, that compiled all identified exposure potential issues at SRS based on the work group's review of Petition SEC 00103. The original 2009 matrix (SC&A, 2009a) was based on issues that were unresolved from the SC&A review of the SRS site profile and SC&A's preliminary review of NIOSH's evaluation report (ER) (NIOSH, 2008). The initial 2009 matrix listed 25 issues of SEC relevance; an additional issue was added later, for 26.

SC&A issued an updated 2014 SEC issues matrix (SC&A, 2014) in February 2014 following the designation of an SEC class for all SRS employees for 1953–1972. This designation rendered moot some SEC issues, while others needed additional research to address questions related to latter time periods, including those for construction trade workers (CTWs), nuclide-specific issues (e.g., neptunium, special tritium compounds, and thorium), and co-exposure modeling. For this current review, SC&A reviewed the 2014 matrix (the latest generated) to confirm any outstanding issues for which documented resolution is not apparent.

Of the 26 SEC-relevant issues listed in the 2014 matrix, three issues lacked a documented resolution: issue 3 for "Recycled Uranium," issue 22 for "Badges not capturing dose," and issue 26 for "additional worker and worker representative issues."

The original recycled uranium (RU) issue, which was identified in SC&A's 2005 site profile review (SC&A, 2005), found that a timeline for RU operations had not been issued and it was not clear when and how RU (with trace radiological contaminants) may have been handled at SRS. NIOSH issued trace contaminant data for RU in 2010 (NIOSH, 2010b), and SC&A responded with a memorandum about remaining RU issues in 2014 (SC&A, 2014b). While there is no confirmation of an outstanding SEC issue, no final resolution was apparent in the work group records on this matter.

For issue 22 (and subsumed issue 23), SC&A had found that worker interviews indicated that some workers kept their badges out of higher radiation areas in order to not exceed dose limits (SC&A, 2011c) and that badge dose readings may have been under-recorded or not recorded. NIOSH was to review SC&A's report of these worker interviews and provide a response.

For issue 26, SC&A had compiled and categorized a number of worker and petitioner comments about specific workplace issues for which a specific NIOSH response has not been received to date. However, as noted in SC&A's updated matrix in this memo, a number of the comments are addressed in existing SEC issues reviewed by the work group and NIOSH.

A number of other SEC-relevant issues from the 2014 matrix have either been closed, resolved, subsumed under other issues, or superseded by the 2011 Board action to recommend an SEC for 1953–1972 (issues 1, 8, 12, 15, 16, 17, 18, 19, 21, 23, 24, and 25). Still others are being

addressed by the development of co-exposure models under ORAUT-OTIB-0081, "Internal Dosimetry Co-Exposure Data for the Savannah River Site": issue 2 for thorium via ORAUT-RPRT-0070 (NIOSH, 2017a) and ORAUT-RPRT-0081 (NIOSH, 2017d); issue 4 for trivalent actinides and thorium; issues 6 and 7 for fission and activation products; issue 9 for tritium; and issue 13 for comparing intakes for CTWs versus non-construction workers. Issue 5 for neptunium (Np)-237 has been addressed by NIOSH in ORAUT-RPRT-0065 (NIOSH, 2016a), ORAUT-RPRT-0077 (NIOSH, 2016b), and ORAUT-RPRT-0080 (NIOSH, 2017c) and is being handled by the work group as an ongoing issue. Issue 10 for special tritium compounds, which are being addressed as "Metal Hydrides" in ORAUT-RPRT-0072 (NIOSH, 2017b), is also ongoing. Issue 11 (exotic radionuclides), issue 14 (special exposure conditions), and issue 20 (tank farm geometry) have reached the resolution stage and are ready for work group review for closure.

Other than the three specific outstanding items—issues 3, 22, and 26, none of which have been judged SEC-significant to date—SC&A has determined that the relevant SEC issues have flowed down to and have been included in subsequent priority action lists presented by NIOSH to the work group. Their status is summarized in SC&A's informal internal update of SEC-00103 issues status in October 2021 (SC&A, 2021).

Given how long ago this 2014 issues matrix was last updated and the challenge faced by SC&A in reconstructing several status items, SC&A recommends to the work group that the 2022 updated matrix[13] included in this memo be reviewed and corroborated by NIOSH and the work group.

[13] Please note that the structure of the 2014 matrix has been updated and the text proofread and reformatted to comply with current NIOSH requirements for Section 508 compliance.

Table A-1. March 2022 update of issues matrix for the SRS SEC petition and petition ER

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
1	Thorium up to 1965	7.1.1.8	Thorium work was carried out in a number of areas and dose reconstruction methods need to be specified. NIOSH had reserved the issue for further research up to 1960 in the ER (NIOSH, 2008), but extended the date to 1965 when it published an addendum to the ER in May 2010 (NIOSH, 2010a).	NIOSH published Addendum 2 to its ER in August 2011 (NIOSH, 2011a) recommending that workers with certain area and dosimetry codes who worked between Jan. 1, 1953, and Sept 30, 1972, be added to the SEC because of the infeasibility of thorium dose reconstruction in certain buildings in this period.	SC&A did an analysis of the completeness of area and dosimetry codes in the records of 10 claimants (not a random sample) (SC&A, 2011e). **Update – February 21, 2014:** This issue is resolved.	Resolved. Board recommended addition of all workers from Jan. 1, 1953, to Sept. 30, 1972, to the SEC. Includes CTWs and non-construction workers (NCWs).
2	Thorium, 1965 onwards	7.1.1.8	Thorium 1965 and after. No coworker model or specific approach to bounding dose was provided in the ER.	Refer to issue 1 up to September 30, 1972. NIOSH is researching the thorium issue after that date.	SC&A has provided draft reports to the Board indicating some thorium work after Sept. 30, 1972. **Update – February 21, 2014:** NIOSH has published Addendum 3 to its ER (NIOSH, 2012a). NIOSH has also published its internal coworker dosimetry data in NIOSH 2013a and a revision of that document (NIOSH, 2013b). SC&A has reviewed NIOSH 2012a and the data relating to thorium that NIOSH proposes to use (SC&A, 2013a). NIOSH has responded to SC&A's review (NIOSH, 2014a). SC&A is reviewing the new information in NIOSH 2013b and NIOSH 2014a and provided its comments during the Work Group meeting held on February 5, 2014, and will provide further comments during the conference call scheduled for February 26, 2014. SC&A's review of NIOSH SRS coworker models is connected with its review of NIOSH's proposal to aggregate internal monitoring data according to a "One Person-One Sample" (OPOS) method, as described in NIOSH 2012b. SC&A's review of the OPOS method, in	Resolved up to Sept. 30, 1972. Open after that.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
					general, has been issued to the SEC work group. SC&A's review of OPOS includes some SRS-specific matters. SC&A's SRS-specific finding is that SRS NCW data cannot be used for the estimation of unmonitored CTW internal doses for a variety of reasons. NIOSH disagrees and contends that it can. **Update – March 2022:** NIOSH issued ORAUT-RPRT-0070, "Evaluation of Method for Assessment of Thorium-232 Exposures at the Savannah River Site from 1972 to 1989" (NIOSH, 2017a). This document discusses a new method for bounding potential internal doses from thorium using known inventories and routine air monitoring data. Following issuance of Addendum 3, NIOSH learned that the method used to analyze urine samples for trivalent radionuclides was changed in 1990 to alpha spectroscopy, which rendered the proposed use of trivalent radionuclide bioassay coworker data impracticable. SC&A provided comments in an October 2018 response (SC&A, 2018), with one finding re alternate sampling methods as applied to decontamination and decommissioning and off-normal sources. NIOSH responded in December 2018 and agreed with SC&A's finding and clarified that "the intake rate associated with these data should only be used for normal conditions," with a 50th percentile co-worker intake applied for off-normal circumstances (NIOSH, 2018, p. 5). This issue appears to be resolved, although work group closure is needed.	

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
3	Recycled uranium (RU)	7.1.1.2	This issue is in part a carry-over from the SC&A technical basis document (TBD) review (SC&A, 2005, p. 71). A timeline for the RU operations has not been published.	Some revised trace contaminant data were provided in July 2010 (NIOSH, 2010b) using U.S. Department of Energy (DOE) RU publications and a 1984 SRS document as references. A start date of 1955 for RU was provided.	SC&A started a review of the NIOSH ratios and associated reference material. Report preparation was stopped pending resolution of issues related to ER addenda. **Update – February 21, 2014:** SC&A is preparing a review of the RU ratios; the review is scheduled to be completed by June 2014. **Update – March 2022:** SC&A issued its review in a memorandum of June 6, 2014, that requested clarification of NIOSH's ratios and associated supporting material. SC&A's major concern was that there were "two different tables provided by NIOSH, and it is not obvious how the values in the tables were derived; therefore, it is difficult to evaluate them" (SC&A, 2014b, p. 2). SC&A recommended to the SRS work group that NIOSH (1) restate and justify their recommended RU components and their appropriate values and (2) provide a description of how the recommended values were derived, so that they can be independently verified. This would include the location in the documents where the values were obtained, any assumptions, conversion factors, and other information necessary to trace the values NIOSH recommends. While no NIOSH response was found, this issue may have been overtaken by other, broader reviews of RU. SC&A believes this to be a matter of clarification, not of SEC significance.	Relevant only after Sept. 30, 1972.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
4	Trivalent actinides americium (Am), curium (Cm), and californium (Cf)	7.1.1.5, 7.1.1.6, 7.1.1.7	Trivalent actinides: Am, Cm, and Cf. There are no data for Cm-244 until 1963 (ER figure 7-1). Data analysis and coworker models have not been provided for any period. Relevance of later data to earlier periods has not been established. Relationship between NCW and CTW intakes for trivalent radionuclides in the period before monitoring began and after monitoring began has not been established. Where NIOSH proposes to use gross alpha data (e.g., for Cf-252, method for selecting workers for assigning dose and selecting the radionuclide) have not been scientifically established. The resulting dose estimates would need to be examined for validity and reasonableness. Cf-252 assignment would also need to be reviewed in relation to spontaneous fission-related organ doses (including neutrons from spontaneous fission after intake).	NIOSH proposes to use measured data or coworker models for estimating dose with sufficient accuracy (ER sections 7.1.1.5 to 7.1.1.7). Since data were collected for all three trivalent radionuclides rather than each separately, NIOSH proposes to assign the result to Cf-252 as appropriate (ER, p. 51). NIOSH has not yet published its coworker model. NIOSH has specified an International Commission on Radiological Protection (ICRP) model for Cf-252 spontaneous fission.	SC&A awaits the coworker model and will review it when it is available. SC&A agrees with NIOSH regarding the ICRP model for Cf-252. **Update – February 21, 2014:** NIOSH has published a coworker model for trivalent actinides (NIOSH, 2012d). Many of the findings for thorium in SC&A 2013a apply to NIOSH's proposed methods for coworker trivalent actinide dose estimation because NIOSH proposes to use trivalent actinide monitoring data for thorium dose reconstruction. Therefore, SC&A has not reviewed NIOSH 2012d as such, pending resolution of the findings in SC&A 2013a that also apply to NIOSH 2012d. SC&A notes that SC&A 2013a does not address adequacy or completeness of SRS trivalent actinide data for coworker modeling of those three radionuclides (Am, Cm, Cf). **Update – March 2022:** SC&A reviewed rev. 03 (NIOSH, 2016c; SC&A, 2017) and rev. 04 (NIOSH, 2019; SC&A, 2020) of ORAUT-OTIB-0081, "Internal Coworker Dosimetry Data for the Savannah River Site," with findings and observations discussed by the work group. Additional reviews were conducted regarding multiple imputation methods and trivalent bioassay variability. Remaining issues are before the work group for discussion and are summarized in the October 25, 2021, internal memorandum, "Updated Status of SEC-00103-Related Issues" (SC&A, 2021).	SC&A has not checked the ending date for these radionuclides. Now only relevant after Sept 30, 1972.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
5	Np-237	7.1.1.4	Data analysis and coworker model not provided. Adequacy of data for coworker model not established. Applicability of back-extrapolation of data from 1960s and after to pre-1960 period not established.	NIOSH proposes to use data for the workers who were monitored to reconstruct their dose and a coworker model for the rest. Data available from 1960 onward in claimant database. NIOSH has not yet published its coworker model.	SC&A awaits the coworker model and will review it when it is available. **Update – February 21, 2014:** NIOSH has published a coworker model for Np-237 (NIOSH, 2012c), which SC&A has reviewed (SC&A, 2013b). NIOSH has responded to SC&A's review (NIOSH, 2014b). SC&A provided its comments regarding NIOSH 2014b at the meeting held on February 5, 2014, and will provide further comments during the during the work group conference call scheduled for February 26, 2014. SC&A's review of NIOSH SRS coworker models is connected to its review of NIOSH's proposal to aggregate internal monitoring data according to an OPOS method (NIOSH, 2012b). SC&A's review of the OPOS method, in general, has been issued to the SEC work group. SC&A's review of OPOS includes some SRS-specific matters. SC&A's SRS-specific finding is that SRS NCW data cannot be used for the estimation of unmonitored CTW internal doses for a variety of reasons. NIOSH disagrees and contends that it can. **Update – March 2022:** NIOSH issued RPRT-0065 (2016a, neptunium operations), RPRT-0077 (2016b, codes), and RPRT-0080 (2017c, Plutonium Fuel Form Facility), with SC&A and NIOSH exchanging responses for all three reports. The outstanding issues await work group discussion and resolution and are summarized in SC&A's October 25, 2021, memorandum, "Updated Status of SEC-00103-Related Issues" (SC&A, 2021).	Now relevant only after Sept. 30, 1972.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
6	Fission and activation products	7.1.1.9	Validity of back-extrapolation of strontium (Sr)-90 data has not been established. Adequacy of fission product monitoring data for coworker model has not been established. ER states that strontium radioisotope monitoring began in the "late 1950s." The proposed coworker model has not been published.	NIOSH has not yet published its coworker model.	SC&A awaits the coworker model and will review it when it is available. **Update – February 21, 2014:** NIOSH has published a coworker model for mixed fission and activation products (NIOSH, 2012e). Some of the findings for thorium and neptunium in SC&A 2013a and SC&A 2013b apply to NIOSH's proposed methods for mixed fission and activation products. SC&A has not reviewed NIOSH 2012e as such, pending resolution of the findings in SC&A 2013a and SC&A 2013b that also apply to NIOSH 2012e. SC&A notes that SC&A 2013a and SC&A 2013b do not address adequacy or completeness of SRS mixed fission and activation product data for coworker modeling of those radionuclides. **Update – March 2022:** SC&A reviewed rev. 03 (NIOSH, 2016c; SC&A, 2017) and rev. 04 (NIOSH, 2019; SC&A, 2020) of ORAUT-OTIB-0081, with findings and observations discussed by the work group. Remaining issues are before the work group for discussion and are summarized in SC&A's informal, internal October 25, 2021, memorandum, "Updated Status of SEC-00103-Related Issues" (SC&A, 2021).	Now relevant only after Sept. 30, 1972.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
7	Co-60	7.1.1.10	Validity of use of fission product data prior to 1960 has not been established. Coworker model has not been published. ER does not address the issue of incidents. Individual bioassay data or coworker model based on claimant data will be used. Targets were encapsulated (comment in TBD matrix). The potential similarity of the irradiation of encapsulated sources is noted in the July 7, 2007, work group meeting notes.	NIOSH has not yet published its coworker model.	SC&A awaits the coworker model and will review it when it is available. **Update – February 21, 2014:** NIOSH covered cobalt (Co)-60 in its report on "exotic radionuclides" (NIOSH, 2012f). NIOSH states that whole body counting data are available. There is no indication of production after October 1, 1972, in NIOSH 2012f. SC&A has not reviewed NIOSH 2012f. **Update – March 2022:** SC&A reviewed rev. 03 (NIOSH, 2016c; SC&A, 2017) and rev. 04 (NIOSH, 2019; SC&A, 2020) of ORAUT-OTIB-0081, with findings and observations discussed by the work group. Remaining issues are before the work group for discussion and are summarized in SC&A's informal, internal October 25, 2021, memorandum, "Updated Status of SEC-00103-Related Issues" (SC&A, 2021).	Now relevant only after Sept. 30, 1972.
8.	Po-210	7.1.1.11	The coworker model has not been published. Incidents are not addressed. Relationship of CTW to NCW intakes has not been established.	NIOSH published a paper on polonium (Po)-210 in January 2011 (NIOSH, 2011b). The Po-210 program at SRS ended in 1970.	No review needed. **Update – February 21, 2014:** NIOSH's report on exotic radionuclides (NIOSH, 2012f) includes further information on Po-210 and does not provide any indication of production of Po-210 after October 1, 1972. SC&A has not further checked the ending date for Po-210 production at SRS. SC&A recommends that this issue be tentatively closed. **Update – March 2022:** Awaits work group action.	Resolved by the Board SEC vote. Ending date may need to be checked.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
9	Tritium	7.1.1.1	NIOSH has not demonstrated that the TBD approach of applying environmental doses to unmonitored workers (no badge, no bioassay) and reporting level to workers with external monitoring only is suitable for unmonitored CTWs. NIOSH has not demonstrated that it has a bounding dose approach for tritium for CTW.	NIOSH published a report on use of tritium data for CTW exposure estimation in November 2010 (NIOSH, 2010c). NIOSH is preparing a second part of this report that specifically addresses CTW vs. NCW exposure.	SC&A published a report that included tritium, comparing CTW and NCW data, in January 2010 (SC&A, 2010b) and another in November (SC&A, 2010c) using a larger tritium bioassay database provided by NIOSH. Both indicate that CTWs had higher bioassays than NCWs in some areas, some periods, and some job types. SC&A will produce a single review of NIOSH's tritium report when the second part is published. **Update – February 21, 2014:** NIOSH published Part 2 of its tritium report in November 2011 (NIOSH, 2011c). SC&A has not resumed its review of tritium-specific issues pending resolution of findings relating to issues 2, 4, 5, and 6, as well as general issues relating to the methods by which CTW and NCW monitoring data can be compared and/or combined (matrix issue 13). **Update – March 2022:** SC&A reviewed rev. 03 (NIOSH, 2016c; SC&A, 2017) and rev. 04 (NIOSH, 2019; SC&A, 2020) of ORAUT-OTIB-0081, with findings and observations discussed by the work group. Remaining issues are before the work group for discussion and are summarized in the October 25, 2021, memorandum, "Updated Status of SEC-00103-Related Issues" (SC&A, 2021).	Only the data from Oct. 1, 1972, onward will be evaluated. There have been tritium/tritides-related data capture visits and interviews (NIOSH and SC&A). SC&A tritium interview summary has been merged with a prior summary of other issues. Combined summary is being sent to DOE for classification review.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
10	Special tritium compounds for CTWs	NA	ER refers to ORAUT-OTIB-0066 (NIOSH, 2007b) for special tritium compound exposure. Relationship of CTW to NCW exposure to special tritium compounds or some other means of bounding CTW exposure to them needs to be established. OTIB-0066, which discusses a method to calculate doses due to exposure to special tritium compounds, is not specific to SRS and does not discuss dose reconstruction issues for such compounds specific to CTWs.	The solubility of one—lanthanum-nickel hydride—is under investigation at SRS. NIOSH is completing a draft of its interview notes.	SC&A awaits the NIOSH approach to estimating tritide doses. **Update – February 21, 2014:** NIOSH has not published any data regarding tritides since the last matrix update in 2011. **Update – March 2022:** NIOSH issued ORAUT-RPRT-0072, "Locations of Stable Metal Tritide Use at the Savannah River Site," in 2017 (NIOSH, 2017b). SC&A reviewed and provided comments in 2018 with a NIOSH response in 2019. No findings to date. Needs work group discussion and resolution.	Refer to issue 9 for interview status.
11	Exotic radionuclides	7.1.1.9 in part	About 150 radionuclides were produced at SRS, and targets were fabricated there (NIOSH, 2006, p. 25). No analysis of the production processes is provided, nor are there any descriptions of incidents. The incident database is incomplete, which was one of SC&A's findings in its TBD review. The lack of analysis may be parallel to the situation at Y-12, where a large number of isotopes were produced, with the difference that at Y-12, they were produced in accelerators, and at SRS, they were produced in reactors. No documentation of the encapsulation processes is provided. The exceptions to the coverage of radionuclides by whole-body counting are not discussed. There is no discussion of whether any of the target materials were themselves radioactive.	NIOSH will respond to the SC&A report on exotic radionuclides. NIOSH will also sort out what other radionuclides were produced that are not in the SC&A report. NIOSH will specify dose reconstruction methods with due attention to the criteria for exotic radionuclides presented by Jim Neton to the Board during the November 2010 Santa Fe Board meeting.	SC&A provided the work group with a report on exotic radionuclides in December 2010 (SC&A, 2010d). **Update – February 21, 2014:** NIOSH published a report on exotic radionuclides in 2012 (NIOSH, 2012f). SC&A 2010d raised a question whether an exotics production program that was proposed in 1969 was ever pursued. NIOSH did not find any evidence that it was (NIOSH, 2012f, p. 12). SC&A has not reviewed this finding. Most of NIOSH 2012f covers the pre-1972 period. SC&A has not further reviewed the periods of exotic radionuclide production beyond that in SC&A 2010d. **Update – March 2022:** No further discussion of this issue is evident. No apparent SEC issues have been found. Awaits work group disposition.	Only relevant after Sept. 30, 1972.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
12	Internal dose due to incidents	5.2.3, 7.3.6	The Special Hazards Investigations list is incomplete. In its Tank Farm Fault Tree Databank, the site acknowledged that many early Tank Farm area incidents were not recorded (until 1965). The ER states that there are incident records, including the Special Hazards Investigation files, and that NIOSH has data relating to incidents (ER, p. 29). No evidence of cover up of incidents was found, and NIOSH can bound dose in any case (ER p. 71).	NIOSH will respond to the SC&A report. NIOSH may follow up with workers interviewed by SC&A.	SC&A prepared a report on extent of and potential gaps in incident documentation in worker records to elaborate on its TBD review finding (SC&A, 2011b). **Update – February 21, 2014:** NIOSH has not responded to SC&A 2011b. The issue remains open. **Update – March 2022:** Work group closed this issue at February 26, 2014, meeting.	Interviews also indicate that there were unrecorded incidents. Only relevant after Sept. 30, 1972.
13	Overall CTW to NCW internal dose relation	7.1	ER states that ORAUT-OTIB-0052 (NIOSH, 2007a) found NCW intakes “were generally higher than construction trades workers” (ER, p. 39). OTIB-0052 suggests a 1:1 ratio for CTW to NCW intakes. SC&A analysis indicates that the assumption that NCW intakes (as indicated by bioassay data) would be generally higher than for CTW is not generally valid. The adequacy of bioassay data for constructing coworker models needs to be examined for different periods, areas, radionuclides, and types of CTWs.	NIOSH has produced an analysis of tritium data comparing CTWs to all workers (including CTWs) (NIOSH, 2010c). NIOSH is preparing a second part comparing CTWs to NCWs. NIOSH is also revising OTIB-0052. NIOSH included both CTWs and NCWs in its thorium SEC recommendation in the ER Addendum 2 (NIOSH, 2011a).	Besides the two reviews of CTWs vs. NCWs (SC&A 2010b and SC&A 2010c), SC&A also produced a report evaluating the plutonium database used in OTIB-0052 (SC&A, 2010e). SC&A also published a master interview summary as part of SC&A 2011b; this summary contains some discussion of CTW vs. NCW matters. SC&A was to review NIOSH’s revision of OTIB-0052 when it is published. SC&A will await instructions on this issue, given the December 8, 2011, Board vote on the SRS SEC to include CTWs and NCWs. **Update – February 21, 2014:** This issue is being covered under the review of coworker models for specific radionuclides as well as in SC&A’s review of the NIOSH’s “One-Person-One-Sample” aggregation of monitoring data. A number of findings relating to CTW dose reconstruction, comparison on NCW and CTW distributions of measurements, and NIOSH’s coworker models remain open. **Update – March 2022:** This issue is subsumed under the work group’s review of OTIB-0081 and the extensive	CTW vs. NCW resolved up to Sept. 30, 1972, by Board vote of 8 Dec. 1972 since both CTW and NCW were included in the SEC recommendation. Also, issues 19 (tentatively) and 21 are closed. A considerable amount of work has been done by NIOSH and SC&A as indicated in the reports cited here. The work group had directed tritium data as the current focus of this issue to be followed by uranium. This is still an outstanding issue for the period after Sept. 30, 1972. Issue may need re-assessment in light of the inclusion of both CTWs and NCWs in the SEC up to Sept. 30, 1972.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
					work group deliberations in 2017–2021 that led to an SEC class being designated for SRS subcontractors for 1972–1990.	
14	Special exposure conditions	7.4.2	There are several areas of concern that can be described as "special exposure conditions," including off-normal or unauthorized work practices, burning of spent tributyl phosphate in open pans in the early years (to 1971), and high exposure potential during certain authorized work practices, such as opening tank risers or cleanup of high-level waste leaks.	NIOSH has stated that it has air concentration data in the burning ground area, and that it will provide a dose reconstruction approach.	Refer to comment column. **Update – February 21, 2014:** This issue has been subsumed under matrix issue 12 for the period October 1, 1972, through 2007.	SC&A worker interviews done as part of the SEC investigation also indicate off-normal practices and high exposure potential during certain types of work, including in the Tank Farms. A master summary of SC&A's interviews (excluding tritides) is in SC&A 2011b. The burning ground issue is no longer relevant, since open pan burning ended in February 1972 (WSRC, 2000, PDF p. 1068).
15	Construction worker job types	NA	Worker intakes and coworker models may have to be built by CTW job type in order to ensure that the models are bounding doses (or more accurate than bounding doses).	NA	**Update – February 21, 2014:** Refer to update for matrix issue 13.	This issue is merged into issue 13.
16	OTIB-0075 validity for SEC use – internal dose	7.1, 7.3.4, 7.4.2	The use of ORAUT-OTIB-0075 (NIOSH, 2009b), which asserts representativeness of claimant data for the whole worker population, for SRS CTW SEC is questionable.	NIOSH also produced a report on data with a significant fraction of "less-than" results that is general, but also applies to the SRS SEC (NIOSH, 2009a).	SC&A reviewed OTIB-0075 (SC&A, 2010b). SC&A also reviewed NIOSH 2009a (SC&A, 2010f). **Update – February 21, 2014:** Refer to update for matrix issue 13	This issue is merged into issue 13.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
17	Early neutron dose to 1961	7.2.2.2	Fig. 7-3 of the ER (p. 65) shows no neutron monitoring data for the 200-F Area until about 1958, and generally less than 20 badges per cycle until 1962 (except for part of 1959). This was “one of the highest neutron-exposure areas at SRS,” according to the ER (p. 64). The entire early period will have to depend almost exclusively on area neutron and photon monitoring data. The relationship of the neutron-to-photon (n/p) ratio data to workers and their personnel neutron exposure experience will need to be established with essentially no reference to actual monitoring data. It is unclear whether there are any early neutron monitoring data for CTWs.	NIOSH will use an approach based on n/p ratios. On Feb. 3, 2011, NIOSH reported no progress on this item, which has been pushed down the list of priorities due to many other action items. NIOSH will provide a date when this will be done. NIOSH stated it has the data to do dose reconstruction.	**Update – February 21, 2014:** This issue has been resolved.	This issue is resolved by the Dec. 8, 2011, Board vote.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
18	Neutron dose 1962–1971	6.2 and 7.2.2	ER acknowledges unmonitored dose at SRS due to neutrons, since monitoring was required only when area neutron dose rates were in excess of 1 mrem per hour. Neutron data are very sparse in general up to the mid-1960s, and sparse even after that. Representativeness of area monitoring for worker exposure and representativeness of available n/p data for all workers in the class needs to be assessed. Additionally, back-extrapolation of post-1972 data was proposed in the TBD. It is unclear whether there will be back-extrapolation to demonstrate bounding dose; if there is, the validity of such back-extrapolation may need to be examined. Validity of assumption of low neutron doses in the reactor areas needs to be examined. Validity of implicit assumption that CTW neutron doses were lower than NCWs needs to be examined in view of the higher bioassay results for some periods and radionuclides, including plutonium in some periods.	NIOSH had stated that it has paired neutron and photon data and may issue a report in March 2011.	**Update – February 21, 2014:** This issue has been resolved.	This issue is resolved by the Board vote of Dec. 8, 2011.
19	Test reactor neutron dose	NA	Neither the ER nor the TBD analyzes the neutron dose at the Heavy Water Components Test Reactor. Issue of an incident was raised in a worker interview done by SC&A.	NIOSH is addressing neutron doses as part of issues 17 and 18.	SC&A research did not result in any specific information about this accident (such as date and accident description). **Update – February 21, 2014:** No information that would warrant a reopening of this issue has come to light since the last matrix update.	One SC&A interviewee indicated an incident took place at this reactor (crack in the core). No further information was available from the interviewee, and no information on such an incident was found in document research done by SC&A. As a result, this issue has been tentatively closed.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
20	Tank Farm exposure geometry	NA	NIOSH to estimate the geometry of exposure in special work situations, such as those described in the F and H Area Tank Farm Fault Tree Databank, and the frequency with which these corrections may need to be applied to external dose. While correction factors can, in principle, be calculated, it is not clear that a scientifically valid set of scenarios, including time worked and radiological conditions, can be constructed. NIOSH has not addressed this issue in the ER.	NIOSH is preparing a model for developing adjustment factors due to geometry of exposure in the Tank Farm.	SC&A will review the NIOSH report when it is published. **Update – February 21, 2014:** NIOSH has stated that it is using MCNP modeling to address this issue. The final model has not been published. This issue was put into a low priority since external dose geometry issues have been satisfactorily resolved in the past and have not been SEC issues (ABRWH, 2013, pp. 57–64).	A more general issue of geometry, and specifically hand exposure, has been raised in worker interviews. NIOSH is preparing a Tank Farm geometry report. Work group needs to address whether work beyond that is needed for SEC review. Open pan burning issue is not relevant since it ended in Feb. 1972.
21	External exposure co-worker data adequacy for CTWs	7.2.1.3	ORAUT-OTIB-0052 (NIOSH, 2007a) is claimant favorable for a large majority of CTWs. However, it is not claimant favorable for some categories. A bounding dose (or better) demonstration needs to be made for all CTW job types.	A suitable adjustment has been made for all CTWs. No further work is needed.	SC&A agrees that existing databases can be used for CTW coworker external dose estimation with appropriate adjustment. This does not include issues 22 and 23, which do not concern coworker data adequacy. Refer to SC&A's review of OTIB-0052 (SC&A, 2007). **Update – February 21, 2014:** This issue has been resolved.	No issue at this time.
22	Badges not capturing dose	NA	SC&A worker interviews suggest that workers kept their badges out of higher radiation areas in order not to exceed dose limits, or sometimes CTWs would be in radiological situations without knowing it (one incident is described when workers were working with radioactive tools thought initially to be clean).	NIOSH will review the SC&A report.	SC&A prepared a report compiling worker issues relating to radiation dose as it was experienced compared to dose that was recorded. This includes matrix issue 23 (SC&A, 2011c). **Update – February 21, 2014:** NIOSH has not responded to SC&A 2011c. **Update – March 2022:** SC&A did not find a response or disposition on this but acknowledges that this is not likely an SEC issue.	No issue at this time.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
23	External dose recording accuracy and completeness	7.3	Petitioners raised the issue of working conditions with high dose rates when badge dose may have been under-recorded or not recorded (such as weekend work) and/or pencil dosimeters were off-scale, or when there are zero doses in the record. An issue connected to this would be whether the HPAREH database reflects actual work experience. Petitioners also state that in some cases, workers thought they were working in clean areas that were then determined to be contaminated.	NIOSH will respond to the SC&A report.	SC&A 2011c covers both matrix issues 22 and 23. **Update – February 21, 2014:** Refer to update on matrix issue 22.	This issue has been merged with issue 22. SC&A prepared a single report on matrix issues 22 and 23.
24	Early monitoring data	Various	The ER has addressed lack of early monitoring data for many workers and radionuclides by a number of devices, including building coworker models, using reporting levels, using air monitoring data, and estimating n/p ratios. While each of these needs to be assessed in its own right (as described in the issues listed in this matrix), an overall assessment of early recordkeeping practices, adherence to procedures, and adequacy of data appears to be warranted.	NA	**Update – February 21, 2014:** This matrix issue has been resolved.	This issue had been merged with other issues but is no longer an SEC issue in view of the Board vote on Dec. 8, 2011.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
25	Environmental dose	None	Using dispersion modeling of stack source terms as described in the TBD and referred to in the ER (p. 72) is not appropriate for onsite SRS workers. For instance, thousands of gallons of solvents contaminated with fission products and plutonium were burned in the burning ground. Use of a Gaussian plume model is not appropriate here, especially for particles greater than half a micron. Furthermore, the resuspension factor does not appear to be claimant favorable and is not entirely appropriate for this class of problem. It may not be claimant favorable by three or four orders of magnitude. Even for stack releases, one potentially significant issue is the non-conservatism of the standard Gaussian model used in the TBD, where it pertains to "non-standardized" short-term releases occurring during stable atmospheric conditions.	Refer to issue 14.	**Update – February 21, 2014:** Merged with issue 14. This matrix issue has been resolved for open pan burning.	This issue has been merged with issue 14. Now resolved since open-pan burning stopped in Feb. 1972. Refer to comment for issue 14.

Matrix issue no.	Issue brief	ER section no.	Issue description	NIOSH issue status	SC&A review status/update	Current status (March 2022)
26	Additional worker and worker representative issues	NA	Worker and petitioner representatives raised various issues during work group meetings and comment periods.	NIOSH will respond to SC&A report.	SC&A compiled a report detailing the issues raised and categorized them, with an indication of where the issue was already covered by an existing matrix issue (SC&A, 2011d). **Update – February 21, 2014:** NIOSH has not provided a specific response to SC&A 2011d. The issues raised in SC&A 2011d are broadly similar to matrix issues 12 and 22/23 in most cases, but workers provided specific additional examples, such as lack of Health Physics coverage in some cases. **Update – March 2022:** While a number of these comments are addressed in other SEC issues reviewed by the work group and NIOSH, a full response is not evident. SC&A acknowledges that none of the issues to date are of apparent SEC significance.	No issue at this time.

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Attachment B: Updated Status of SEC-00103-Related Issues

This attachment is a February 2022 update to an informal, internal memorandum that SC&A sent to the Savannah River Site (SRS) and SEC Issues work groups and the National Institute for Occupational Safety and Health (NIOSH) on October 25, 2021. SC&A updated the memo based on a technical call with NIOSH on January 12, 2022, and provides it here for the convenience of the work groups.

Much of the focus over the past 3–4 years has been on the question of bioassay completeness for subcontractors at SRS. Given the Advisory Board on Radiation and Worker Health's (Board's) recommendation and subsequent action by the Secretary of Health and Human Services (HHS) to designate a Special Exposure Cohort (SEC) class for 1972–1990 for subcontractors, SC&A believes it now useful to revisit the status of remaining SEC-related actions. To that end, we have drafted for SRS and SEC Issues work groups and NIOSH review an updated matrix of previously identified issues that have been addressed by the work group. The purpose is to achieve agreement on what issues and actions remain for SEC-00103.

The attached status and milestones are based on available reports, meeting transcripts, and notes. In most cases, for issues stemming from the co-exposure model reviews and radionuclide-specific issues (e.g., neptunium, thorium, and metal hydrides), NIOSH and SC&A have already exchanged reviews and responses and await work group discussion, review, or closure. In the case of subcontractor bioassay data completeness, the joint work groups have recently tasked SC&A with completing its review for 1991–2007.

In terms of recent milestones, the SRS and SEC Issues work groups last met on March 23, 2021, to discuss the proposed SEC class for subcontractor construction trade workers (sCTWs). The full Board met and voted on the work groups' proposal on April 15, 2021, with a letter recommending an SEC class sent to the HHS Secretary on July 12, 2021. That class was approved and designated by the HHS Secretary on August 18 and became effective on September 17, 2021.

In terms of the other SEC issues, the SRS and SEC Issues work groups last met to discuss issues such as neptunium and thorium in 2017, with additional NIOSH and SC&A reports on those subjects issued in 2018 and 2019.

Based on work group and NIOSH input, we will revise the attached matrix to be a basis for further discussion.

Table B-1. Status Summary of SEC Actions: Savannah River Site (SEC-00103)

SEC issue	Source documents	SEC period	Recent actions	Status/Resolution	Notes
Co-exposure models	**OTIB-0081** (internal coworker dosimetry data): Rev. 03: 11/22/2016 Rev. 04: 3/13/2020 Rev. 05: 9/1/2020	Construction trade workers (CTWs): 1972–1998 sCTWs: 1991–1998	SC&A reviewed rev. 04 on 9/4/2019 and then issued a revision of that review on 3/13/2020 (rev. 1 of SC&A's review)	Work group (WG) closed findings 2–5 and all observations in December 2019 and November 2020. Finding 1 subsumed under trivalent bioassay response (refer to next row)	Awaits joint SEC/SRS WG group action (presentations were made to joint WGs on 11/17/2020 and 11/20/2020)
Data adequacy	**Trivalent bioassay variability** (response papers by NIOSH and SC&A)	1972–1998	SC&A response: 6/3/2020 NIOSH response: 10/21/2020	SC&A and NIOSH held technical call in February 2021; resolution of SC&A's original questions likely to require an SC&A site visit/data capture and/or subject matter expert interviews (to be discussed with WG). NIOSH to complete updated co-exposure model including coefficient of variation analysis of trivalent data (pending).	Presentations were made to joint WGs on 11/20/2020. Awaits SC&A followup with a summary status memorandum for WG discussion of the issue and any potential path forward. Also, awaits NIOSH statistical analysis of variation in OTIB-0081, rev. 06.
Stratification	**OTIB-0075: Construction trade worker (CTW) stratification refinement** Rev. 01: 6/17/2016	1972–1998	NIOSH white paper: 5/28/2019 SC&A plutonium (Pu) memo: 11/12/2019 NIOSH Pu response: 3/4/2020	No further activity, other than status presentations to Board	Awaits joint SEC/SRS WG group action (presentations were made to joint WGs 11/17/2020 & 11/20/2020)

SEC issue	Source documents	SEC period	Recent actions	Status/Resolution	Notes
Neptunium exposures	**RPRT-0065** (neptunium operations) Rev. 0: 9/19/2016 **RPRT-0077** (codes) Rev. 0: 11/8/2016 **RPRT-0080** (Plutonium Fuel Form Facility) Rev. 0: 2/7/2017	1972–1995 1973–1989 1973–1977	SC&A reviewed and NIOSH responded for all three reports. SC&A's review dates: **RPRT-0065:** 3/13/2017 **RPRT-0077:** 4/10/2017 **RPRT-0080:** 8/2/2017	**RPRT-0065:** NIOSH responses to 2 SC&A findings (5/23/2017) **RPRT-0077:** NIOSH responses to all SC&A findings/observations (1/30/2018) **RPRT-0080:** NIOSH responses to 3 SC&A findings (1/30/2018)	Awaits joint SRS/SEC WG action
Thorium exposures	**RPRT-0070** (Th-232) (5/15/2017) **RPRT-0081** (thoron) (4/7/2017)	1972–1995	**RPRT-0070:** SC&A had 1 finding (10/11/2018) **RPRT-0081:** SC&A had 1 observation (10/11/2018)	NIOSH responses to all findings and observations **RPRT-0070:** 12/17/2018 **RPRT-0081:** 6/27/2019	Awaits joint SRS/SEC WG action
Metal hydrides	**RPRT-0072** (1/9/2017)	Early 1980s–2007	**RPRT-0072:** SC&A had several comments (8/3/2018)	NIOSH responses to all SC&A comments (1/4/2019)	No findings – needs WG action
Bioassay data for DuPont-era subcontractors (RPRT-0092)	**RPRT-0092** **RPRT-0091** **RPRT-0094**	1972–1990	Board recommends SEC class for sCTWs 7/12/2021	SEC class designated 8/18/2021	SEC class effective 9/17/2021
Bioassay data for Westinghouse-era subcontractors (RPRT-0092)	**RPRT-0092** **RPRT-0091** **RPRT-0094**	1991–1998	SC&A tasked Sept. 2021	To be determined	Ongoing

Index of Reports Cited in Attachment B

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RPRT-0065: National Institute for Occupational Safety and Health. (2016b). *An evaluation of neptunium operations at Savannah River Site* (ORAUT-RPRT-0065, rev. 00). https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-65-r0.pdf

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RPRT-0072: National Institute for Occupational Safety and Health. (2017b). *Locations of stable metal tritide use at the Savannah River Site* (ORAUT-RPRT-0072, rev. 00). https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-72-r0.pdf

RPRT-0077: National Institute for Occupational Safety and Health. (2016c). *Evaluation of Health Physics Area and Health Physics Department codes to identify neptunium workers at the Savannah River Site* (ORAUT-RPRT-0077, rev. 00). https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-77-r0.pdf

RPRT-0080: National Institute for Occupational Safety and Health. (2017c). *Potential neptunium exposure to plutonium fuel facility construction workers in Building 235-F at the Savannah River Site* (ORAUT-RPRT-0080, rev. 00). https://ww.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-80-r0.pdf

RPRT-0081: National Institute for Occupational Safety and Health. (2017d). *Appropriateness of using 1997 gross alpha air sampling data as a method of bounding thoron intakes at the SRS H Area Tank Farm between 1972 and 1994* (ORAUT-RPRT-0081, rev. 00). https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-81-r0.pdf

RPRT-0091: National Institute for Occupational Safety and Health. (2019a). *Evaluation of Savannah River Site americium-241 source terms between 1971 and 1999 using bioassay frequency tables* (ORAUT-RPRT-0091, rev. 00). https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-91-r0-508.pdf

RPRT-0092: National Institute for Occupational Safety and Health. (2019b). *Evaluation of bioassay data for subcontracted construction trade workers at the Savannah River Site* (ORAUT-RPRT-0092, rev. 00). https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-92-r0-508.pdf

RPRT-0094: National Institute for Occupational Safety and Health. (2019c). *Bioassay for subcontractor construction trade workers at the Savannah River Site from 1972 to 1997* (ORAUT-RPRT-0094, rev. 00). https://www.cdc.gov/niosh/ocas/pdfs/orau/oraurpts/or-rprt-94-r0-508.pdf

Trivalent Bioassay Variability:

National Institute for Occupational Safety and Health. (2020b). *Response to SC&A memorandum, "Summary position on trivalent bioassay variability"* [Response paper]. https://ftp.cdc.gov/pub/FOIAREQ/183766-508.pdf

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