Assessment and Resolution of DRPs at Zion Nuclear Power Station

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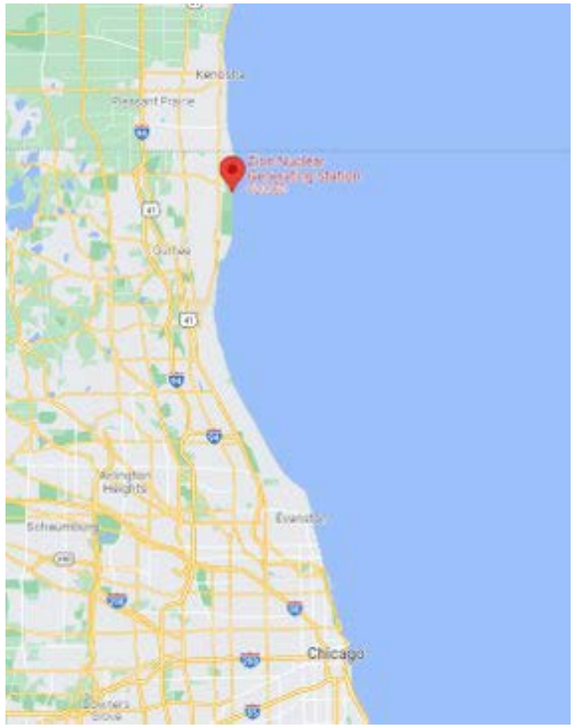
Overview

- Zion Decommissioning Project up to 2022
- Discovery of Discrete Radioactive Particles (DRPs)
- Initial attempts to assess impact of DRPs
- Efforts to understand the DRP situation
- Enlisting Office of Research and ORISE to assist with evaluating survey techniques and potential impacts
- NRC’s innovative approach to the 2023 Confirmatory Survey
- Resolution of DRPs
- New guidance to share with Industry

Zion Decommissioning Project



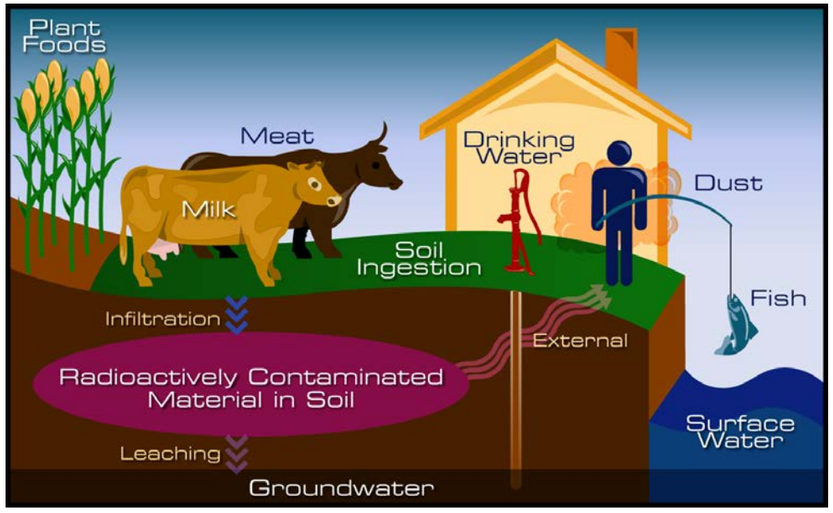
- Zion Units 1 and 2 permanently ceased operations in February 1998
- Decommissioning activities beginning 2010
- The original Post Shutdown Decommissioning Activities Report (PSDAR), submitted in February 2000, described an approach where the site would enter a period of SAFSTOR dormancy from approximately 2000-2015, with license termination occurring by 2026
- The license termination plan (LTP) for the site was submitted in December 2014 and approved in September 2018
- The LTP was silent on DRPs

Discrete Radioactive Particles Onsite

- The licensee did not address DRPs as part of its LTP because the operational history of the site and pre-decommissioning surveys led to the conclusion that none were present before decommissioning started.
- Since 2012, as part of the decommissioning activities, hundreds of discrete radioactive particles had been transported to outdoor areas of the site during the decommissioning process, including certain site areas that had already received final surveys.
- The licensee knew about the particles and had been removing them up to and during the time of the LTP review.
- Although other sites have addressed DRPs during decommissioning, there was little existing guidance, making it difficult to address DRP contamination during this final stage of the decommissioning process.
- Staff elected to pursue a verification survey in April 2021 to assess this issue (expected/hoped to find no DRPs but instead found 9 DRPs in a limited survey, including a fuel flea)

Why are DRPs an Issue?

- A DRP is a relatively high activity particle, insoluble in water...essentially a point source
  - Spent fuel particles from fuel rod failures
  - Activated metal from component wear during reactor operations
  - Activated metal and concrete chips or cuttings from segmentation activities using saws or other methods
- Typical residual radioactivity at time of license termination is diffuse material in soil, structures, or groundwater
  - RESRAD or DandD (environmental pathways software) are used to establish a conceptual site model and derive DCGLs for demonstrating compliance at 25 mrem/y
- DCGLs are not applicable for assessing DRPs nor is surveying for “point” sources addressed in MARSSIM



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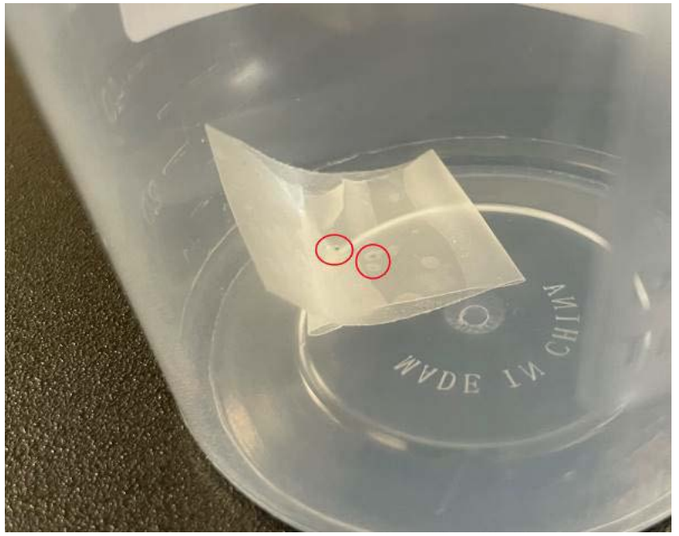
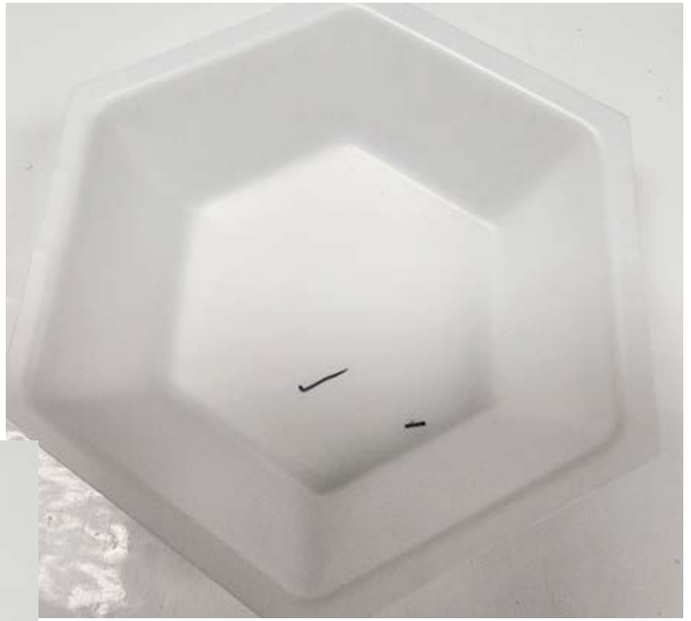




Initial Attempts to assess impact of DRPs

Table 5.2. Summary of Particle Total Activities (pCi)[a]

Sample	Am-241	Ba-133	Cm-244	Co-60	Cs-134	Cs-137	Eu-152	Eu-154	Eu-155	Np-237	Pu-238	Pu-239[b]	Sr-90
S0112A	0.0			**48400**	36	-27	-20	-40				0.059	-0.21
S0116	0.			**18400**	22	-4	-28	0				0.041	-0.34
S0120	0.0			**378**	11	0.6	**20000**	**1100**	13	-0.011	**0.043**	**0.063**	0.83
S0124	0.12	-300	0.06	**1508000**	1200	1000	-500	2000	-10	0.020	**0.14**	**0.079**	0.49
S0126	**79900**	-11	**14800**	**62**	12	**98900**	-70	**2920**	**838**	**3.9[c]**	**26188**	**7540**	**157043**
S204AEu	0.028	**1520**				-	**344000**	**16200**	-	-0.028	-0.028	**16.6**	0.8

[a]Bolded values indicate did not include zero

[b]Pu-239 value includes contributions from Pu-240

[c]Result is statistically positive, however, review of the alpha spectrum indicated tha tely the result of Pu-242

Neutron activation of reactor corrosion products. NaI response was near background levels. Sample was difficult to isolate and collect. Technician used a shovel to remove soil approximately 50 cm in diameter.

Sample was easy to collect. Neutron activation of the reactor bioshield (e.g., Eu-152, Eu-154, Ba-133).

On surface. Irradiated fuel fragment. Sample was easy to collect. Technician was able to scoop material with hand trowel.

Less than 15 cm from surface. Sample required effort to isolate and collect. Neutron activation of the reactor bioshield (e.g., Eu-152, Eu-154, Ba-133).

Preliminary Dose Estimates

Preliminary HQ Dose Estimates: Particles Collected During April 2021 Zion Survey
(07/08/2021)

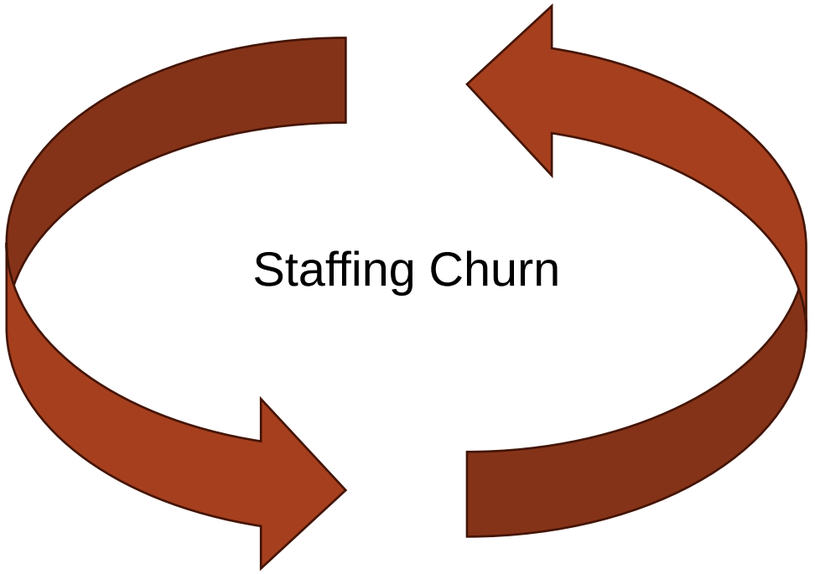
Particle Type (Sample ID) [a]	Inhalation dose (mrem/yr)		Ingestion dose (mrem/yr)			Skin contact; shallow dose equivalent (mrem) [j]	Skin contact; deep dose equivalent (mrem) [j]
	ICRP 30 adult [f]	ICRP 72 age-dependent [g]	ICRP 30 adult	ICRP 72 age-dependent [h]	ICRP-72 age-dependent [j]		
Fuel (S-126) [b]	49,300	677 to 32,000	329 [k]	118 to 1,910	4 to 42	5,230	4
Concrete (S-204) [c]	92	2 to 179	3	2 to 28	2 to 15	2,070	25
Concrete (S-120) [d]	5	<1 to 10	<1	<1 to 1	<1	114	1
Act. Metal (S-124) [e]	328	9 to 683	15	19 to 301	9 to 67	9,470	192
Act. Metal (S-112A) [e]	11	<1 to 22	<1	<1 to 10	<1 to 2	303	6
Act. Metal (S-116) [e]	4	<1 to 8	<1	<1 to 4	<1	114	2

a	There are no measurements of particle sizes. It is not known whether the particles containing the radioactivity were visible to the human eye.
b	Radionuclides measured: ^{60}Co, ^{90}Sr, ^{137}Cs, ^{154}Eu, ^{155}Eu, ^{238}Pu, ^{239}Pu, ^{241}Am, and ^{244}Cm.
c	Radionuclides measured: ^{60}Co, ^{133}Ba, ^{152}Eu, ^{154}Eu, and ^{239}Pu.
d	Radionuclides measured: ^{60}Co, ^{152}Eu, and ^{154}Eu.
e	Radionuclide measured: ^{60}Co.
f	ICRP 30 adult doses shown for 1 micron activity median aerodynamic diameter (AMAD).
g	Range of age-dependent doses shown for 0.3 to 100 microns, and ages 3 months (newborn) to 20 years (adult).
h	Range of age-dependent doses shown for 3 months (newborn) to 20 years (adult), and *default* ICRP f1 values.
j	Assumes no uptake (dose coefficients generated using DCAL 9.4 with *f1* = 1E-30). • This bounding case is unrealistic for all particles. • In comparison, ICRP-134, ICRP-137, and ICRP-141 (technical basis documents for ICRP-100 Human Alimentary Tract Model) contain information on ingestion of irradiated fuel fragments, with *f* values ranging from 0.2 to 5E-6 for the radionuclides in this table.
j	Skin dose calculated using VARSKIN 6.2.1, assuming each particle is spherical with a 100 µm diameter, Zeff=56, density=2.4 g/cm^3, and using radionuclide data from ICRP-38 w/ daughters present, except for isotopes of Pu, Am, and Cm. The assumed exposure time is 24 hours.
k	Region III estimated an ingestion dose of 273 mrem/yr assuming the particle only contained 75 nCi of ^{241}Am.

RAIs and Discussions with the Licensee

Biggest Questions:
How good were the surveys for DRPs?
What could have been “missed?”
What is the potential impact to an average member of the critical group?

Licensee Responses



Management Interactions

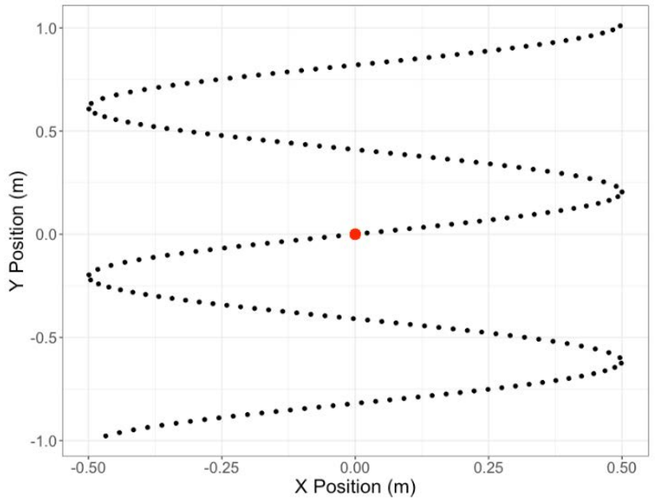
Research (mostly complete by late 2022)
Scan MDA for DRPs (ORISE)
DCFs for DRPs (RES&RCD)

Progress

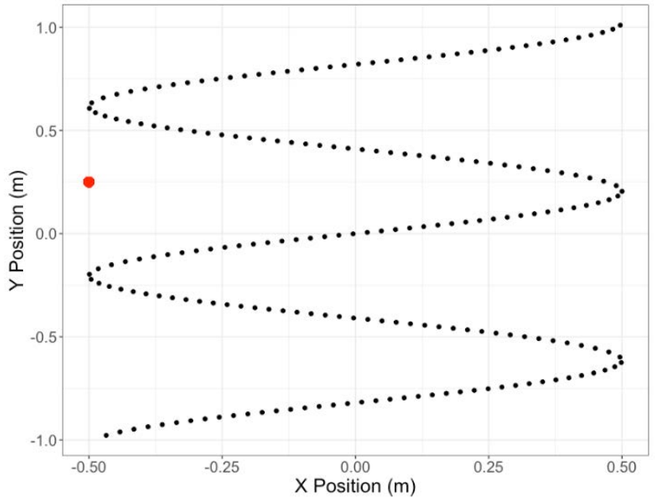
- Spring 2023, the licensee declared they had removed all “known” DRPs from the site and that the site was considered releasable.
- Staff determined a confirmatory survey would provide reasonable assurance that the site was releasable:
  - Developed criteria (i.e., no “risk significant” DRPs)
    - Established a dose level that was “risk significant” for DRPs
      - No deterministic effects
      - Stochastic dose (TEDE) not to exceed public dose limits
    - Worked with ORISE to develop survey plan
      - Surface & Subsurface soil
  - Any DRP identified to be collected an analyzed
  - Plan was reviewed by both management and licensee
  - Survey conducted over 3 weeks (non-concurrent) during 2023 with licensee assistance for excavation
  - Extent of condition survey conducted by licensee afterwards (other areas that became suspect during confirmatory survey)

Scan Sensitivities ML24004A133

Optimistic



Pessimistic



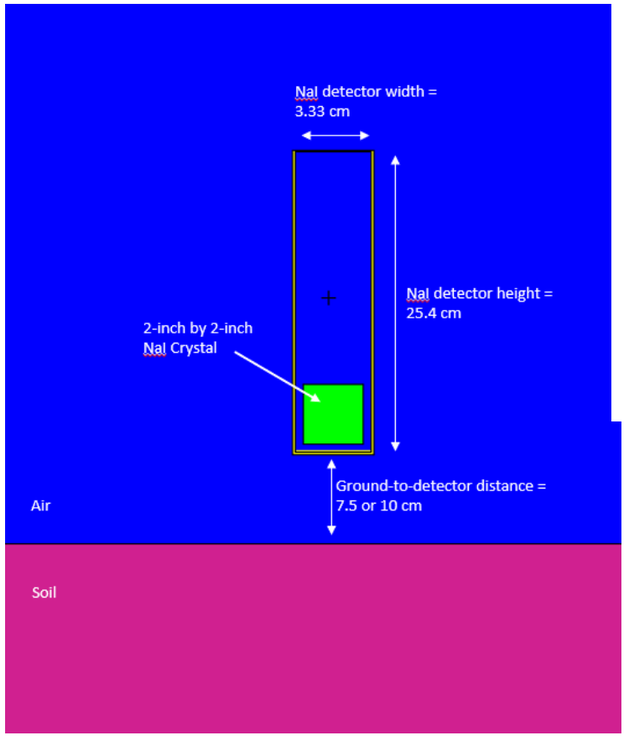


Table 4.1. DRP scan MDA for various scan conditions and a surveyor velocity of 0.25 m/s (µCi)

Particle Depth in Soil	Radionuclide and Ground-to-Detector Distance							
	Co-60		Cs-137		Th-232		Am-241	
	7.5 cm	10 cm	7.5 cm	10 cm	7.5 cm	10 cm	7.5 cm	10 cm
Optimistic Scenario (Figure 2.1a)								
Surface	0.09	0.11	0.16	0.21	0.04	0.05	0.35	0.45
7.5 cm	0.15	0.18	0.33	0.38	0.12	0.13	-	-
15 cm	0.31	0.34	0.77	0.85	0.29	0.33	-	-
30 cm	1.2	-	4.2	-	-	-	-	-
Pessimistic Scenario (Figure 2.1b)								
Surface	0.37	0.38	0.74	0.75	0.19	0.19	1.7	1.7
7.5 cm	0.70	0.67	1.8	1.6	0.66	0.61	-	-
15 cm	1.2	1.1	3.4	3.2	1.3	1.3	-	-
30 cm	3.4	-	14.1	-	-	-	-	-

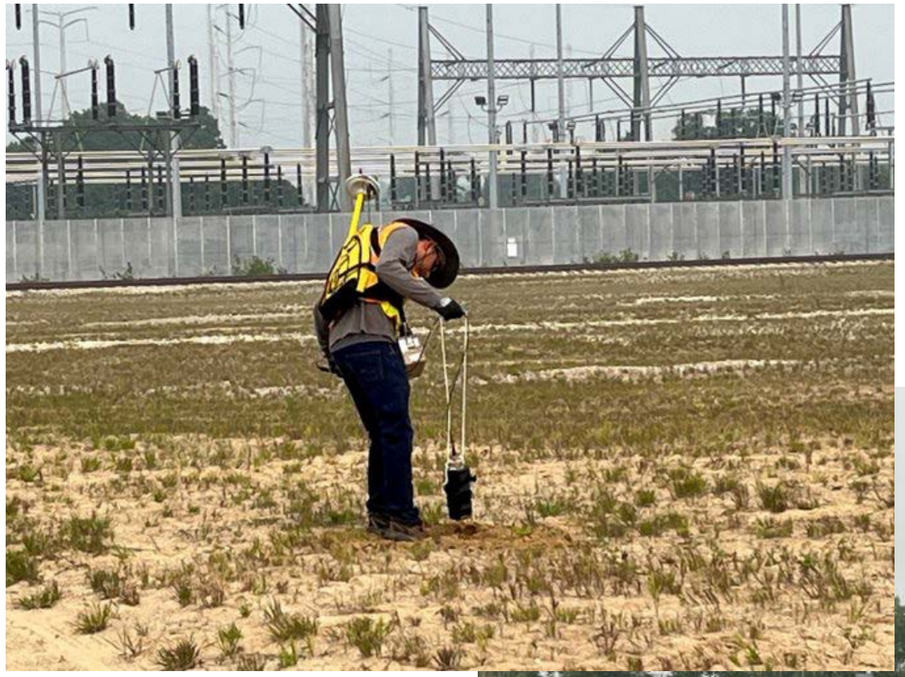
"–" indicates the calculation shows the DRP cannot be identified during scans.
All values rounded to two significant digits or the hundredth position.

Table 4.2. DRP scan MDA for various scan conditions and a surveyor velocity of 0.5 m/s (µCi)

Particle Depth in Soil	Radionuclide and Ground-to-Detector Distance							
	Co-60		Cs-137		Th-232		Am-241	
	7.5 cm	10 cm	7.5 cm	10 cm	7.5 cm	10 cm	7.5 cm	10 cm
Optimistic Scenario (Figure 2.1a)								
Surface	0.12	0.15	0.23	0.29	0.06	0.07	0.50	0.63
7.5 cm	0.22	0.25	0.47	0.54	0.16	0.19	-	-
15 cm	0.43	0.48	1.09	1.2	0.41	0.46	-	-
30 cm	1.7	-	5.9	-	-	-	-	-
Pessimistic Scenario (Figure 2.1b)								
Surface	0.52	0.53	1.0	1.1	0.27	0.28	2.4	2.4
7.5 cm	0.99	0.94	2.5	2.3	0.93	0.86	-	-
15 cm	1.7	1.6	4.9	4.6	1.9	1.8	-	-
30 cm	4.9	-	20	-	-	-	-	-

"–" indicates the calculation shows the DRP cannot be identified during scans.
All values rounded to two significant digits or the hundredth position.

Surface and Subsurface Soil Surveys



Confirmatory Survey/Extent of Condition Survey Results

- No DRPs found in subsurface soil
- 13 DRPs found/collected in surface soil
  - All either activated metal (10) or activated concrete (3)

Particle Type	Co-60 Min (uCi)	Co-60 Max (uCi)
Activated Metal	0.014	0.38
Activated Concrete	5.7E-4	3.0 E-3

Laboratory Results (data entered in pCi; spreadsheet calculates Bq for dose calculations)

	DRP		DRP		DRP		Concrete		Concrete		Concrete		DRP		
Sample ID	5375M0001		5375M0002		5375M0003		5375M0004-1		5375M0004-2		5375M0005		5375M0006		
	pCi	Bq	pCi	Bq	pCi	Bq	pCi	Bq	pCi	Bq	pCi	Bq	pCi	Bq	
Co-60	**5.31E+04**	1.96E+03	**8.21E+04**	3.04E+03	**1.18E+05**	4.37E+03	**5.70E+02**	2.11E+01	**9.70E+02**	3.59E+01	**3.04E+03**	1.12E+02	**3.83E+05**	1.42E+04	
Ni-59	0	0.00E+00	0	0.00E+00	0	0.00E+00	**2.30E+01**	8.51E-01	0	0.00E+00	0	0.00E+00	0	0.00E+00	
Ni-63	0	0.00E+00	0	0.00E+00	**5.20E+05**	1.92E+04	**6.90E+01**	2.55E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	
Sr-90	0	0.00E+00	0	0.00E+00	**2.4**	8.88E-02	1.3	4.81E-02	0	0.00E+00	0	0.00E+00	0	0.00E+00	
Ba-133	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	**1.00E+02**	3.70E+00	0	0.00E+00	
Cs-137	0	0.00E+00	0	0.00E+00	0	0.00E+00	**0.00E+00**	0.00E+00	0	0.00E+00	**2.40E+01**	8.88E-01	**1.43E+02**	5.29E+00	
Eu-152	0	0.00E+00	0	0.00E+00	0	0.00E+00	**4.60E+03**	1.70E+02	**1.55E+04**	5.74E+02	**6.06E+04**	2.24E+03	0	0.00E+00	
Eu-154	0	0.00E+00	0	0.00E+00	0	0.00E+00	**2.90E+02**	1.07E+01	**1.05E+03**	3.89E+01	**4.37E+03**	1.62E+02	0	0.00E+00	
Eu-155	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	
Pu-238	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	
Pu-239	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	
Am-241	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	
Cm-244	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	

How to generically assess hypothetical DRP dose

- Develop hypothetical scenario with time frames and routes of exposure (most likely hypothetical exposure)
- Practical evaluations of sampling of particles (size/applicability to hypothetical exposure pathways)
- Dose coefficients: ML23136A207

EDE Dose Coefficients (Sv/Bq h)			
Nuclide	External Chest Surface	Upper Respiratory Tract	Gastrointestinal Tract
Stellite 6			
Co-60	5.80E-10	8.80E-08	2.70E-09
Inconnel 718			
Ni-59	4.60E-13	2.80E-09	3.50E-10
Ni-62	0.00E+00	0.00E+00	0.00E+00
Regulatory Concrete			
Fe-55	4.10E-14	2.60E-09	2.40E-10
Co-60	5.80E-10	8.80E-08	2.70E-09
Ba-133	5.50E-09	2.30E-08	1.40E-08
Eu-152	1.30E-08	4.10E-08	2.90E-08
Eu-154	1.40E-08	4.30E-08	3.00E-08

Table 9. CEDE coefficients for ingested DRPs other than fuel fragme

CEDE Coefficient (Sv/Bq)	
Stellite (Z = 33; ρ = 8.4 g/cm^3)	
Co-60	1.80E-09
Inconel (Z = 29; ρ = 8.2 g/cm^3)	
Ni-59	2.90E-11
Ni-63	7.10E-11
NRC Concrete (Z = 10; ρ = 2.3 g/cm^3)	
Fe-55	2.40E-11
Co-60	1.80E-09
Ba-133	5.20E-10
Eu-152	1.20E-09
Eu-154	1.90E-09

Assessment of Zion Site DRPs

- At conclusion of surveys
  - NRC staff needed reasonable assurance that no risk significant DRPs remain
    - ✓ Conservative Assumption: A small probability some DRPs may still be present
      - Best represented by DRPs collected during last surveys
      - The potential exposure of a member of the public to a DRP had to be considered
      - Assess as a “less likely but probable” scenario
    - ✓ For a DRP to not be of “risk significance”
      - Potential dose to avg member of critical group should be <100 mrem TEDE
      - No potential for deterministic effects (e.g., skin dose/ LDE < 50 rem)
    - ✓ Scenario considered: construction worker
      - Is most likely to be doing work that would resuspend a particle (inhalation/ingestion)
      - May take “long lunch” – nap for 2 hrs on ground (skin/direct exposure)
      - Particle could be stuck on skin until showering – 12 hr (skin/direct exposure)

Assessing potential for inhalation and ingestion

- Estimating DRP aerodynamic equivalent sizes
  - Given measured activity in particles
  - Given licensee site characterization for max material activity densities for concrete and metal
  - Simple geometry calculations
  - Given methods in ICRP 66 for aerodynamic equivalency

For Concrete:

$$Volume\ (cm^3) = {Activity_{Co-60}}/{Max\ Concentration_{Co-60} * \rho}$$

$$Volume\ (cm^3) = {570\ pCi}\Big/{1{,}090\frac{pCi}{g} * 2.35\ g/cm^3} = 0.223\ cm^3$$

$$Volume_{sphere}\ (cm^3) = \frac{4}{3}\pi r^3$$

$$r = \sqrt[3]{\frac{3}{4\pi} Volume_{sphere}\ (cm^3)}$$

$$d_{ae} = d_e \sqrt{\frac{\rho}{\chi}}$$

Estimating DRP aerodynamic equivalent sizes

For Metal Particle:

$$Volume_{sphere} = \frac{1.42E-2\ \mu Ci}{4.06E4\ \mu Ci/cm^3} = 3.5E-7\ cm^3$$

$$d_e = 2r = 2 * \sqrt[3]{\frac{3}{4\pi} 3.5E-7 (cm^3)} = 0.0087\ cm = 87\ \mu m$$

$$d_{ae} = 87\ \mu m * \sqrt{\frac{8}{1.5}} = 201\ \mu m$$

Estimated Size of DRPs			
from RAI 10 Response		equivlent	aerodynamic
	cc	diameter (um)	diameter (um)
M1	1.3E-06	136	313
M2	2E-06	157	362
M3	2.9E-06	177	409
M4-1	0.22253	7518	9411
M4-2	0.37868	8976	11235
M5	1.1868	13136	16442
M6	9.4E-06	262	605
M7	7E-06	237	548
M8	1.3E-06	136	314
M9	4.2E-07	93	214
M10	3.5E-07	87	202
M11	3.1E-06	180	416
ZS	4.7E-06	207	478

Initial Conclusions: All particles exceed 100 µm aerodynamic diameter so are not likely inhaled. Smallest concrete particle is still large (0.22 cm^3) so is also not likely to be accidently ingested nor stuck on skin for 12 hr.

- Assessing ingestion and skin/LDE dose
  - Use RDC dose coefficients (CEDE/SDE/LDE)
  - Use generic frame estimates for time in GI tract
  - Use 2 or 12 hr time frames for skin dose estimate

Transit Times	Typical Range	Max	GI Tract Mean Residence Times (hrs) from ICRP 30	
Upper Resp Tract	1-2 days	2 days	Stomach	1
Small Intestine	1.8-8 hrs	10 hrs	Small Intestine	4
Large Intestine	~36 hrs	5 days	Upper Large Intestine	13
			Lower Large Intesting	24

Most Activated Metal DRP		
Hypothetical Dose Category (Assumptions)	**Calculated Dose**	**Public Dose Limit (TEDE)***
Effective Dose Equivalent (EDE) (located on upper torso for 12 hours)	9.9 mrem	100 mrem/y
Committed Effective Dose Equivalent (CEDE) (assuming ingested)	2.6 mrem	100 mrem/y
Most Activated Concrete DRP		
EDE (in contact with skin on upper torso for 2 hours)	6.3 mrem	100 mrem/y

*TEDE is the sum of EDE and CEDE exposures when both an internal and external dose occur

Additional Dose Estimates	Calculated Dose	Applicable limit
Most activity Metal DRP located on skin for 12 hr	374 mrem SDE	50,000 mrem
Most activity Metal DRP LDE dose in GI tract (24 hr in LI)	1,600 mrem LDE	50,000 mrem
Most activity Concrete DRP located on skin for 2 hr	15 mrem SDE	50,000 mrem

Additional Dose Estimates	Calculated Dose	Applicable limit
Metal DRP @ 100 μm aerodynamic diameter in RT for 1 day and cleared through GI tract	9.2 mrem EDE	100 mrem
0.7 μCi Co-60 DRP (sensitivity limit in Table 4.1 for pessimistic scenario at 7.5 cm depth)	19.8 mrem EDE (2x the most activated metal DRP dose estimate)	100 mrem

Final Conclusions on DRPs at the Zion site:

- Encountering a DRP at the site is very unlikely
  - Multiple scans have taken place (licensee and NRC contractor) and all DRPs identified have been removed
  - No subsurface DRPs found in representative sampling
- If any DRPs remain, the activity will decay consistent with respective radionuclide half-lives
- Doses from any DRPs encountered by the public at the site are unlikely to exceed the public dose limit or cause deterministic effects, decreasing as they decay.

Document No./Title	Date	Notes
Issuance of Dose Coefficients (DC) for Discrete Radioactive Particles (DRPs) (ML23136A178) and Ulcerations Threshold Recommendations (ML23136A207) technical reports.	May 2023 and September 2022	Renaissance Code Development (RCD) published two reports on dosimetry for discrete radioactive particles in decommissioning.
Estimating Scan Minimum Detectable Activities of Discrete Radioactive Particles (ML24004A133)	January 2024 (final)	Discusses survey of DRPs and provides information on calculation of scan MDAs for select radionuclides, depths and offset distances. No substantive changes were made to the final.
Issuance of Information Notice 2024-01, Minimization and Control of Contamination Involving Discrete Radioactive Particles at Decommissioning Facilities (ML23195A074)	February 2024	Provides information to inform licensees of recent challenges involving detection and contamination control of hot particles or discrete radioactive particles during plant operations and decommissioning.
Issuance of: Interim Staff Guidance: Contamination Control, Radiological Survey, and Dose Modeling Considerations To Support License Termination at Sites With Environmental Discrete Radioactive Particle Contamination DUWP-ISG-03 (DRAFT)	September 26, 2024	The guidance is focused on contamination control, radiological survey and dose modeling considerations for decommissioning sites with the potential for environmental discrete radioactive particle contamination. The Federal Register Notice 89 FR 78917 announcing availability of the ISG for public comment was issued on September 26, 2024. The public comment period ends on October 28, 2024.

Thank you