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Sampling for Confidence: Guidance for Evaluating the Quality of Canister Sampling Plans

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EXECUTIVE SUMMARY

There is a need for an inspection frequency that demonstrates reasonable assurance that the confinement function of dual-purpose-canisters (DPCs) is maintained as these DPCs are returned to storage service following transportation. The DPCs contain spent fuel from shutdown reactor sites.

The currently-proposed 100% DPC inspection frequency is overly conservative and unnecessary to demonstrate reasonable assurance that the confinement function of all DPCs is maintained for return to storage service. Testing all DPCs does not appropriately reflect the very low risk of leakage (i.e., low probability based on design and low consequences based on analysis). Currently, there are 1066 DPCs forecast to be loaded at reactor sites which either are shutdown or plan to cease operations by 2025. These DPCs may be transported by rail in sets of 3 to 5 DPCs per shipment. Assuming each rail consist originates at a single reactor site, an alternative proposal to test one canister/consist/site would result in 356 to 214 canisters, respectively, being tested given the population of 1,066 canisters

This Savannah River National Laboratory (SRNL) report outlines statistically-based, random sampling plans that provide guidance on the number of samples of these canisters that are needed to establish bounds on the quality of the outcome of such sampling. The quality of each proposed sampling plan is expressed in the form of a statement that the number of undetected, unacceptable canisters in the population is less than some number, call it D, at a high level of confidence. In addition, evaluations using a similar approach for random sampling at the proposed levels of 214 and 356 canisters are provided.

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LIST OF ABBREVIATIONS

CFR	Code of Federal Regulations
DOE	Department of Energy
DOE-NE	Department of Energy – Office of Nuclear Energy
DPC	Dual-purpose Canister
ISF	Interim Storage Facility
ISPFSI	Independent Spent Fuel Storage Installation
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act (of 1982) as amended
SFP	Spent Fuel Pool
SNF	Spent Nuclear Fuel
SRNL	Savannah River National Laboratory

1.0 Introduction

The Nuclear Waste Policy Act of 1982, as amended, (NWPA) [1] established the federal government's responsibility to accept Spent Nuclear Fuel (SNF) and high-level radioactive waste (HLW) from waste owners and generators for ultimate disposition. SNF generated by the current fleet of commercial nuclear reactors is being stored at the reactor sites in spent fuel pools (SFPs) and in dry independent spent fuel storage installations (ISFSIs), with a limited amount of SNF being stored in away-from-reactor ISFSIs (pool storage at Morris, Il).

The Department of Energy – Office of Nuclear Energy (DOE-NE) is developing attributes, options, and supporting analyses to enable future-informed choices about how best to manage SNF from commercial nuclear power reactors and to integrate these choices with the ultimate disposition of DOE managed SNF and high-level radioactive wastes. Multiple SNF management options include the receipt and return to storage, without re-packaging, of spent fuel from shutdown reactor sites that is contained in dual-purpose canisters (DPCs). The DPCs will be transported to a repository or Interim Storage Facility (ISF) by rail within certified transportation casks. Acceptance methods and criteria for evaluating the condition of the dry storage canisters after transportation and prior to returning the canisters to storage service at the ISF requires development and must include licensing considerations.

The Nuclear Regulatory Commission (NRC) has indicated [2] that additional guidance is required for scenarios in which the existing DPCs currently in service at ISFSI's under 10 Code of Federal Regulations (CFR) Part 72 [3] are transported under 10 CFR Part 71 [4] and subsequently returned to storage under 10 CFR Part 72. This guidance development has started and early NRC discussions [2] indicate acceptance testing to demonstrate confinement will be required on some number of DPCs received at an ISF or repository before returning the DPCs to storage service.

The currently-proposed 100% DPC inspection frequency is overly conservative and unnecessary to demonstrate reasonable assurance that the confinement function of all DPCs is maintained for return to storage service. Testing all DPCs does not appropriately reflect the very low risk of leakage (i.e., low probability based on design and low consequences based on analysis). Currently there are 1066 DPCs forecast to be loaded at reactor sites which either are shutdown or plan to cease operations by 2025. These DPCs may be transported by rail in sets of 3 to 5 DPCs per shipment. Assuming each rail consist originates at a single reactor site, an alternative proposal to test one canister/consist/site would result in 356 to 214 canisters, respectively, being tested given the population of 1,066 canisters.

The purpose of this document is to provide guidance in the form of random sampling schema that will provide bounds on the outcome of such sampling (expressed using the metric of unacceptable canisters that remain, undetected, in the population), if all sampled canisters are found to be acceptable. In addition, evaluations using similar metrics for random sampling at the proposed levels of 214 and 356 canisters are provided.

2.0 Sampling for Confidence

2.1 Statistical Approach

Each of the canisters in the population of interest may be classified as acceptable or unacceptable. The purpose of evaluating a sample of these canisters is to provide an estimate of the quality of the unsampled portion of the population. To meet the objectives for this evaluation, the sampling must be sufficient to be able to conclude that the number of unacceptable canisters that remain in the unsampled portion of the population is adequate at an adequate confidence level. The approach used for this evaluation is a simple case of the method proposed by Wallenius [5], which relies on the hypergeometric distribution [6].

Thus, for this evaluation the number of canisters in the sample, n, was determined using a hypergeometric distribution, which provides the probability of d errors being found in a sample (without replacement) of n items from a population of N items within which a total of D items is in error. This probability may be expressed as

$$H(N,n,D;d) = \frac{\binom{D}{d}\binom{N-D}{n-d}}{\binom{N}{n}} \qquad \text{for } 0 \leq d \leq \min\{n, D\}$$

where

$$\binom{x}{y} = \frac{x!}{y! \cdot (x-y)!}$$

and x! is x factorial where the factorial of any positive integer x is written x! = x•(x-1) • (x-2) •…•3•2•1 and 0! is defined to be 1.

Once again, anticipating that the number of unacceptable canisters, d, in the sample will be zero, the value of n was selected so that the probability of finding d=0 unacceptable canisters in the sample for a population of N = 1066 canisters with D or more unacceptable canisters is less than a small fraction, α. Thus, after the sampling effort is successfully completed (i.e., no unacceptable canisters are found in the sample of n canisters), there is (1- α) ×100% confidence that the number of unacceptable canisters that remain in the unsampled portion of the population is less than D. This is true given that if there were D or more unacceptable canisters in the population, the sampling used would have found at least one of the unacceptable canisters with probability of (1 - α) ×100%. Obviously, the greater the number, n, of sampled canisters without any unacceptable ones from the population, the greater the confidence will be in the conclusion that the number of unacceptable canisters in the unsampled portion of the population is less than D.

For a given value of α, the sample size is to be the smallest possible integer, n_0, such that

$$H(N, n_0, D; d) = H(1066, n_0, D; 0) \leq \alpha$$

One way to determine n_0 is to note that evaluating H(N, n, D; 0) for n=1 gives

$$H(N,1,D;0) = \frac{N-D}{N}$$

and that for $n \geq 2$

$$H(N,n,D;0) = \frac{N-(n-1)-D}{N-(n-1)} \cdot H(N,n-1,D;0)$$

This second equation may be computed for increasing values of n until n_0 is determined. A Microsoft Excel workbook was developed to support these evaluations utilizing the iterative nature of these computations. As examples, spreadsheets in the workbook were used for the determination of values for n_0 for the situations provided in Table 2-1, each with a confidence level of at least 95%, where N is the population size, x is the number of unacceptable canisters found in the random sample of n canisters, and D is the number of unacceptable canisters in the original population of N canisters.

Table 2-1. Values Needed for Sample Size, n_0, for Sampling to Provide 95% Confidence

N	x	n_0	D	Confidence (1-α)	D as a % of N
1066	0	58	53	0.952264779	4.972 < 5%
1066	0	72	42	0.950075640	3.940 < 4%
1066	0	97	31	0.950316610	2.908 < 3%
1066	0	141	21	0.950699546	1.970 < 2%
1066	0	275	10	0.950137480	0.938 < 1%

The interpretation of each row of Table 2-1 is similar to the following: For the first row, if a random sample of 58 canisters is inspected and no unacceptable canisters are found, then there is more than 95% confidence that less than 53 canisters or 5% of the original population is unacceptable.

2.2 Determination of Additional Sample Sizes

With this framework understood, a more detailed look at sampling options may be explored as provided in Table 2-2, which answers the question: How many canisters must be sampled (n_0) and found to be acceptable to allow for the following statement: There is at least (1-α)100% confidence that there are fewer than D unacceptable canisters in the population of interest?

Table 2-2. Values Needed for Sample Size, n_0, for Sampling to Designated Confidence Level

N	D	D as a % of N	Confidence (1-α)100%	n_0
1066	53	5%	95%	58
			96%	62
			97%	67
			98%	74
			99%	87
	42	4%	95%	72
			96%	78
			97%	84
			98%	93
			99%	109
	31	3%	95%	97
			96%	104
			97%	113
			98%	125
			99%	146
	21	2%	95%	141
			96%	151
			97%	163
			98%	180
			99%	208
	10	1%	95%	275
			96%	293
			97%	314
			98%	344
			99%	392

2.3 Evaluation of Select Sample Sizes

If a random sample of size 214 or 356 were taken and no unacceptable canisters were found, then what would be the confidence level for 1 to 5% defectives or what would be a bound on the number of defectives at 95 to 99% confidence? Excel spreadsheets were developed to answer these questions, and the spreadsheets yielded the results provided in Table 2-3 and Table 2-4.

Table 2-3. Confidence Levels Associated with 214 and 356 Sample Sizes for Various Values of D

n	D	D as a % of N (1066)	Confidence (1-α) ×100%
214	53	5%	99.9995%
	42	4%	99.9934%
	31	3%	99.9140%
	21	2%	99.1399%
	10	1%	89.4758%
356	53	5%	~100%
	42	4%	~100%
	31	3%	99.9997%
	21	2%	99.9822%
	10	1%	98.3183%

Table 2-4. Bounding D Values Associated with 214 and 356 Sample Sizes for Various Confidence Levels

n	Confidence (1-α) ×100%	D	D as a % of N (1066)
214	95%	14	1.3%
	96%	15	1.4%
	97%	16	1.5%
	98%	18	1.7%
	99%	21	2.0%
356	95%	8	0.75%
	96%	8	0.75%
	97%	9	0.84%
	98%	10	0.94%
	99%	12	1.13%

The interpretation of each row of Table 2-3 is similar to the following: For the last row of the n=214 information, if a random sample of 214 canisters is inspected and no unacceptable canisters are found, then there is at least 89% confidence that less than 1% of the original population (i.e., fewer than 10 canisters) could be unacceptable. The interpretation of each row of Table 2-4 is similar to the following: For the first two rows of the n=356 information, if a random sample of 356 canisters is inspected and no unacceptable canisters are found, then with at least 95% confidence there are fewer than 8 (0.75%) of the original population that could be unacceptable. In fact, the confidence level of this conclusion is at least 96%. If the number of unacceptable canisters of interest were 7, a random sampling plan of 356 canisters with an outcome of no unacceptable canisters would have an associated confidence level that falls slightly below the 95% confidence level.

2.4 Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

3.0 Conclusions

There is a need for an inspection frequency that demonstrates reasonable assurance that the confinement function of dual-purpose-canisters (DPCs) is maintained as these DPCs are returned to storage service following transportation without re-packaging. The DPCs contain spent fuel from shutdown reactor sites.

The currently-proposed 100% DPC inspection frequency is overly conservative and unnecessary to demonstrate reasonable assurance that the confinement function of all DPCs is maintained for return to storage service. Testing all DPCs does not appropriately reflect the very low risk of leakage (i.e., low probability based on design and low consequences based on analysis). The alternative proposal to test one canister/consist/site would result in 214 to 356 canisters being tested given a population of 1,066 canisters expected from reactor sites shutdown prior to 2025.

This report outlines statistically-based, random sampling plans that provide guidance that will identify bounds on the outcome of such sampling (expressed using the metric of unacceptable canisters that remain, undetected, in the population), if all sampled canisters are found to be acceptable. In addition, evaluations using similar metrics for random sampling at the proposed levels of 214 and 356 canisters are provided.

4.0 References

[1] *Nuclear Waste Policy Act of 1982, as Amended*, United States Code, Title 42, Chapter 108, 2010.

[2] Guidance Development for a Storage – Transport – Storage Interface, NRC Division of Spent Fuel Management Regulatory Conference (REG CON), 2018.

[3] Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste and Reactor Related Greater Than Class C Waste, *Code of Federal Regulations*, Title 10, Part 72.

[4] Packaging and Transportation of Radioactive Material, *Code of Federal Regulations*, Title 10, Part 71.

[5] Wallenius, K.T., "Sampling for Confidence," **Journal of the American Statistical Association**, Volume 62, Issue 318, pp 540-547, June 1967.

[6] Mitra, Amitava, **Fundamentals of Quality Control and Improvement**, Third Edition, John Wiley & Sons, Inc., Hoboken, NJ, 2008.

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