2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

Sample size determination in radioactive waste characterization using value of information as a criterion.

P. S. Cabrera[1] and R. Vicente[2]

[1] palomascabrera@gmail.com, *IPEN, Av. Lineu Prestes, 2242, Cidade Universitária, São Paulo, SP*
[2] rvicente@ipen.br, *IPEN, Av. Lineu Prestes, 2242, Cidade Universitária, São Paulo, SP*

1. Introduction

In Brazil, the Provisional Measure No. 1049, published in May 2021, created the National Nuclear Safety Agency (in Portuguese, Agência Nacional de Segurança Nuclear, ANSN). Thus, all laws governing the Brazilian nuclear sector changed, including the Law No. 10,308, which provides the regulation for radioactive waste disposal facilities. As of 2021, the ANSN is responsible for licensing all types of radioactive waste disposal, while the National Nuclear Energy Commission (in Portuguese, Comissão Nacional de Energia Nuclear, CNEN) must design, build, install, manage and operate the intermediate and final radioactive waste disposal facilities.

The country has intermediate disposal facilities at CNEN institutes, but it still does not have a final disposal facility in operation. The project for the National Repository of Radioactive Wastes of Low- and Medium-Level is under development and the start of operations is scheduled for 2025.

The national nuclear regulation CNEN NN 8.01 (2014) requires that the radionuclides and their activities in each waste package, as presented for disposal, are accurately reported. However, a large volume of radioactive waste was generated before the issuance of the regulation, thus a large volume of stored radioactive waste needs to be characterized in respect to its radionuclide content. In Table I, the radioactive waste preliminary inventory, to which this work applies, is presented.

Table I: Preliminary inventory of radioactive waste awaiting characterization in Brazil.

Local	**Class** (CNEN NN 8.01)	**Origen**	**Description**
Angra 1 and Angra 2 (in operation, RJ)	2.1	Filters from the primary circuit of PWR reactors	- 10.000 packages - mass ~200 a 400 kg each package - dose rate ~ 0,7mSv/h (1m)
Decommissioning Unit in São Paulo (UDSP, INB) (deactivated, SP)	2.3	Rare-earth metals production, closed in 1992	- 1179 t, in about 10.000 packages. - dose rate ~ 20 µSv/h (surface).
Caldas (deactivated, MG) Caetité (in operation, BA)	2.3	Mining	- 2302 t, mesothorium, grounded silos - 1500 t, mining tailings dam - 10159 t, grounded concrete silos
Carapina (in operation, ES) Macaé (in operation, RJ)	2.3	Oil and gas exploration	- stored in drums - ~1000 new drums per year

Sample size calculation

If using only classical statistic, the calculation of the number of samples depends on the choice of confidence level and the margin of error. To expose the impact of these choices on the final number of samples, consider an inventory of N = 10,000 radioactive waste packages and margin of error multiple of the standard deviation (σ). The Fig. 1 presents the number samples for different values of confidence level and margin of error varying between 1% and 40% of σ. In the graph shown, it is evident that the number of samples is highly dependent on the values chosen for the sampling calculation factors.

Sample Size for Differents Confidence Levels and Confidence Intervals

Confidence Level (%) \ Confidence Interval (% of σ)	1%	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%
99	8694	2938	1561	942	624	442	328	253	201	164	136	114	98	84	73	65	57	51	46	41
95	7935	1936	964	566	370	260	192	148	117	95	79	66	57	49	43	37	33	30	27	24
92	7560	1622	792	462	300	211	156	120	95	77	64	53	46	39	34	30	27	24	21	19
90	7314	1454	703	408	265	186	137	105	83	68	56	47	40	35	30	27	23	21	19	17
85	6747	1147	545	314	203	142	105	80	64	52	43	36	31	26	23	20	18	16	14	13
80	6247	942	442	253	164	114	84	65	51	41	34	29	25	21	18	16	14	13	12	10
75	5542	721	334	191	123	86	63	48	38	31	26	22	18	16	14	12	11	10	9	8
70	5196	633	292	166	107	75	55	42	33	27	22	19	16	14	12	11	9	8	7	7
68	5000	588	270	154	99	69	51	39	31	25	21	17	15	13	11	10	9	8	7	6
65	4638	513	235	133	86	60	44	34	27	22	18	15	13	11	10	8	7	7	6	5
60	4195	432	197	112	72	50	37	28	22	18	15	13	11	9	8	7	6	6	5	5

Figure 1: Sample size for different confidence levels and confidence intervals.

Thus, when calculating the number of samples to be collected to characterize a large set of radioactive waste packages, let us assume two situations:

Situation A. We could adopt the common knowledge and use a confidence level greater than 80%. In this way a large number of packages would be sampled to obtain experimental values closer to the true values. However, a large number of samples increase the financial expenses with the sampling process and radiological protection, in addition to implying greater detriment to human health.

Situation B. It is possible to adopt undemanding values for the input parameters in the graph in Fig. 1 and carry out a small sampling. In this case, the financial cost of the sampling process as well as the exposure of the operators will probably be reduced. However, in this situation it is highly possible that the experimental values are so far from the true values that the characterization obtained is unreliable, which can lead to incorrect radioactive waste management.

The situations A and B exemplify an evident problem when the volume of waste to be characterized is very large, as is the case with the current Brazilian inventory. Knowledge about the wastes impacts directly in its management. On the one hand, when promoting radioactive waste characterization, spending time and resources to achieve high accuracy results may be unnecessary - knowing the magnitude order of the radionuclide activities may be sufficient. On the other hand, negligent characterization may not guarantee correct management. Therefore, the choice of the number of samples for the characterization must be justified, even if it is adopted, as a principle that it is in favour of safety.

Despite the statistic limitations, some common sense ideas are widely used in all areas of human knowledge. In general, a confidence level greater than 80% is required and considered a parameter that defines the credibility and practical significance of a scientific study. Ordinarily, only a classical inferential statistic is used to define the sample size. However, many questions have been raised about the requirement for high confidence levels. Bacchetti mentions that, despite being widespread, this concept has flaws and depends on an implicit assumption that there is a well-defined boundary between an adequate and inadequate sample size, which can be calculated [4]. This interpretation harms scientific research, as it leads to incorrect publications and wasted resources.

Objectives. This work intends to communicate the beginning of a direct PhD project in which we propose to incorporate the Value of Information (VOI) concept in the radioactive waste characterization process so that the costs of the sampling and analysis process are justified in light of the optimization principle of radiological protection. We intend to consider the financial cost, the cost of radiological protection, the radiological detriment and the foundations of the ALARA (As Low As Reasonably Achievable) to determine a method to calculate the ideal number of samples applicable to the characterization of radioactive waste and complementary to classical statistics method. Thus, we will define a tool for making more legitimate decisions that justify investments (financial and human).

2. Methodology

The VOI analysis is a quantitative method for estimating the expected gain from a reduction in the uncertainty of a data collection and can be used to determine the sampling size or to assess the cost-effectiveness of a research project. It is based on Bayesian statistics, where a probability does not represent a relative frequency, but is interpreted as a degree of conviction about plausible values for a parameter [3].

In the current literature, examples of VOI general applications and suggestions for methods to calculate the sample size are found [5], as well as applications in public health, industry, clinical and epidemiological studies [1], medicine, agricultural production, gas exploration [2]. However, the VOI concept has not yet been applied to radioactive waste. This work aims to apply it specifically in the characterization stage, incorporating the financial cost and the human detriment by exposure to ionizing radiation in the sample size calculation.

Thus, it is intended to provide an easy-to-use tool for decision-making and contribute to the optimization of radiological protection in the characterization process, which will impact not only the management of radioactive waste from the current inventory, but also the management of future waste.

3. Results and Discussion

The project will be conducted in the Radioactive Waste Management Service of the Nuclear and Energy Research Institute. This group search for solutions to national problems and run studies on all stages of radioactive waste management. At this moment the project is in initial implementation phase and results was not produced yet, but we intend to maintain communication with the others professionals in the nuclear area and be open for cooperation in the sense to promote solutions for the radioactive wastes in Brazil.

4. Conclusions

Actions to improve the radioactive waste management are essentials for the Brazilian nuclear area. The country has growth projections to the area, as projects for a new nuclear power plant (Angra 3) and a Brazilian Multipurpose Reactor, however, does not have a final disposal facility for radioactive waste. The project for the National Repository of Radioactive Wastes of Low- and Medium-Level is under development and the start of operations is scheduled for 2025.

In 2021, the creation of the National Nuclear Safety Agency (ANSN) has already changed the national regulations, including the regulations on radioactive waste management and disposal. As of 2021, the ANSN assumes the responsible for licensing all types of radioactive waste disposal, while the National Nuclear Energy Commission (CNEN) must design, build, install, manage and operate the intermediate and final radioactive waste disposal facilities. The moment is conducive for revision and change in the legislation and methods, specially applied to radioactive wastes.

We communicate in this work the beginning of a direct PhD in which we propose incorporate the Value of Information (VOI) concept in the radioactive waste characterization process. We intend to create a method to calculate the ideal sample size, applied to radioactive waste characterization, considering the financial cost, the cost of radiological protection, the radiological detriment and the foundations of the ALARA (As Low As Reasonably Achievable). It will be a tool for making more legitimate decisions that justify investments (financial and human). The project will be conducted in the Radioactive Waste Management Service of the Nuclear and Energy Research Institute, a CNEN organ in São Paulo.

Acknowledgements

Our acknowledgment to the organization of the International Nuclear Atlantic Conference 2021, as well as all the participants of the event, and the group from the Radioactive Waste Management Service of the Nuclear and Energy Research Institute of the National Nuclear Energy Commission.

References

[1] A. R. Willan, “Optimal sample size determinations from an industry perspective based on the expected value of information”, *Clinical Trials*, vol. 5, 587–594 (2008).

[2] C. H. Campani, R. Guimarães, R. D. Nascimento. “Quantificando o valor da informação: estudo de caso de um projeto de exploração e produção de gás natural”, *E&G Economia e Gestão*, v. 19, n. 53, 73-87 (2019).

[3] E. C. F. Wilson, “A practical guide to value of information analysis”, *PharmacoEconomics*, vol. 33, 105-121 (2015).

[4] P. Bacchetti, “Current sample size conventions: flaws, harms and alternatives*”, BMC Medicine*, vol 8, 17 (2010).

[5] P. Bacchetti, C. E. McCulloch, M. R. Segal,R. Simon, P. Muller, G. L. Rosner, J. A. Hanley, S. Shapiro, “Simple, defensible sample sizes based on cost efficiency”, *Biometrics*, 64(2), 577–594 (2008).

[6] S. T. Ziliak, D. N. McCloskey. *The cult of statistical significance: How the standard error costs us jobs, justice and lives,* Ann Arbor: University of Michigan Press, Michigan, U.S.A. (2008).

[7] S. T. Ziliak, D. N. McCloskey. “The cult of statistical significance”, *Proceedings of JSM – Joint Statistical Meeting*, Washington, U.S.A., Aug. 1-6 (2009).