Improved Clearance Verification for Sites – 25729

Jonatan Jiselmark [1]*, Steve Adams **, Robert Meck ***
* Green Field Strategies AB
** Private Consultant
*** Private Consultant
[1]Corresponding Author, E-mail: jonatan@greenfieldstrategies.se

KEYWORDS: MCSOF, Clearance, Uncertainties, System understanding, MARSSIM

ABSTRACT

There are several methods for clearance of land used around the world today. None that addresses all known uncertainties and generates the probability of complying with the clearance criterion while at the same time is usable for planning remediation and cost minimization. Employing the method described in this paper (MCSOF) ensures a cost-effective remediation and a high probability of complying with the clearance criterion.

A recent paper by Meck and Jiselmark [1] described a method for improved verification of clearance by implementing the sum of fractions rule (SOF). Significantly, the method accounts for all known uncertainties including those from the scenario modelling. Previous verifications that clearance criteria were met simply applied the concentration of a radionuclide per annual dose, Sv/a per Bq/m^2 or Bq/g, for each radionuclide as a constant with no associated uncertainty. The MCSOF method incorporates those uncertainties and the uncertainty of all known parameters in simulated calculations.
The present work demonstrates the application of this method to a real site and presents some of the major advantages to this method for clearance of land. For example:

- a method non-dependent on assumed distributions,
- a method that handles variations of radionuclide contamination within the site,
- a method that handles uncertainty for all known parameters used to calculate Bq/g,
- a proven cost-effective remediation and clearance method.

INTRODUCTION

Radioactive contaminants may harm people in different ways. Some nuclides are short lived and some are long lived. Some are radiating gamma rays and are harmful through external radiation and some are radiating alpha- or beta particles and should not be ingested or inhaled, some are both. Some nuclides are migrating with ease, and some are fixed. Understanding the system in how radioactive nuclides can cause harm is a central part for generating site specific radiotoxicity calculations for different nuclides [2].

Dependent upon the contaminants and the natural system where they are located, different dose scenarios can be dominating during different time periods. To perform site specific radiotoxicity calculations, site specific parameters need to be known. Using known uncertainties regarding the radiotoxicity parameters together with known uncertainties regarding the radioactive content, the sum of fractions (SOF) can be calculated using Monte Carlo simulations as demonstrated in a previous paper [1].

Clearance is the termination of regulatory control of radioactivity on land, buildings, materials, equipment and in liquids. It is usually based on the dose to the average individual of the critical group for a limiting scenario of that group [3]. In nearly all cases, measurements and calculations are the basis for demonstrating that clearance criteria have been met. Consequently, that demonstration is based on the analysis of multiple measurements. Clearance is fundamentally an estimate of doses in the future, and accurate dose estimates with accurately quantified uncertainties usually have not been calculated. There are many methods for estimation of uncertainties used for clearance. Whenever possible and appropriate, annual doses should be reported as a distribution of possible values rather than as a single point value [3].

We have developed a method for calculating the average dose to individuals in the critical group that makes no a priori assumptions about the radionuclides concentration distribution but uses the actual distribution of survey and sampling measurements. The actual distribution of measurements seldom, if ever, fit a defined distribution e.g., Poisson, Gaussian, log-normal, or uniform distribution. Our method described here does not need or use a defined distribution. Rather, the distribution of the survey and sampling data itself is used. Thus, our method is not overly conservative and is a more accurate calculation.

It applies Monte Carlo Sum of Fractions (MCSOF) that account for all known uncertainties and defines the probability and uncertainty in complying with the clearance criterion. And the results are shown in a distribution of possible values.

The effective dose to a member of a critical group should be kept below the dose constraints of 300 µSv annually, and there is no need for the ALARA principle below the limit 10 µSv annually [4].

This article demonstrates the application of MCSOF to real data from a real site and incorporates the known uncertainties of the input parameters. In this work all of the scanning or discrete measurements themselves are the distribution and are used directly to assess the compliance with clearance criteria while accounting for all known uncertainties. In the work described below we used data from the final status survey for the purpose of demonstrating the applicability of the MCSOF method. Additionally, we investigate the possibility to optimize a clearance project on cost instead of doses for those areas where MCSOF calculates a dose less than 10 µSv per year. This is investigated in detail in another paper which is in preparation.

ICPR publication 82 discusses the variance of contaminants and that this issue needs to be addressed on a case-by-case basis [3]. We have handled this by analyzing the effect of the size of the contaminated soil area for different dose scenarios. All dose scenarios are dependent on mean contaminations at different areas. For example, external radiation is dominating from the area closest to a person's location. Also, doses received through ingesting contaminated water from a well depend on the average concentration at the whole groundwater area for the well. The areas for different scenarios in this article are called integrated areas. The size of the integrated areas has been calculated using RESRAD ONSITE for each dose scenario for SU-1 [5].

A site can be cleared if the contamination is so low that no scenario will generate a yearly dose greater than the internationally accepted limit. The integrated area for the limiting scenario will give the maximum size for a survey unit. If all survey units are cleared, the site can be cleared. Scenarios with smaller integrated areas sets the limit for the variance within the survey unit. We define the p^{th} percentile probability of the SOF as SOF_p, where p is chosen arbitrarily. For illustrative purposes in this work, we use SOF_{95}. Clearance is possible when the mean value of SOF is below 1. The uncertainty of the SOF calculations is shown as a distribution of possible values. The SOF_{95} is chosen as the value along this distribution that shows the mean including its uncertainty. Proving that $SOF_{95} < 1$ using all known uncertainties and a clearance limit of 10 µSv per year allows the possibility to optimize on other parameters than dose [4].

MATERIALS AND METHODS

We analyzed the measurements and the information from a previously performed remediation and clearance project performed by others for a site in US. The Final Status Survey and Sampling procedures and work control requirements were defined by a previous contractor. The data we use here for illustrative purposes are from the Final Status Survey of Survey Unit 1 (SU-1). (Note here that the division of the whole site into survey units has been made without the integrated areas in mind.)

Description of the site

SU-1 is the name of the site we used for this work. SU-1 is in the southwest portion of the former building basement where research, development, fabrication and testing of uranium-aluminum and uranium stainless steel fuel assemblies for nuclear reactors using 2.7 to 3.9 percent mass enrichment of uranium-235 (^{235}U). In addition, fabrication of aircraft components using magnesium-thorium alloy (4 percent thorium as thorium-232 (^{232}Th)) and construction of thermal-electric nuclear generators that were strontium/yttrium-90 (^{90}Sr/Y) fueled and mercury cooled and thermo-electric generators using encapsulated plutonium-238. These activities were conducted from 1956 to 1969. Starting in 1969 the contents of the building were removed, the building was decontaminated, and demolished down to the foundation and basement floor. The Atomic Energy Commission (AEC) license was terminated on December 29, 1970.

Previous to the current site work, radiological surveys and sampling were conducted before and after demolition of the building. Historical evidence, field data, and the conceptual site model indicate that facility surfaces and systems were contaminated from radiological operations. Gamma surveys of the underlying soil and piping systems in the former building footprint were performed. Based on historical use and data, the primary radionuclides of concern (ROC) are low enriched uranium (^{234}U, ^{235}U, and ^{238}U). Historical soil sample results under the building slab demonstrate that ^{232}Th concentrations are consistent with background and ^{90}Sr/Y was not detected. Therefore, ^{232}Th and ^{90}Sr/Y are not considered ROCs.

Scanning measurements

A total of 9784 scanning measurements of the surface soil were made. Inductively coupled plasma mass spectrometry (ICP-MS) analysis of the material collected from process drains and soil samples demonstrated that ^{234}U contributed 70 – 80 percent of the uranium radioactivity. MicroShield® code calculations demonstrated that >99.99 percent of the gamma flux from ^{234,235,238}U was in the range of 60 keV to 200 keV [6]. The final status survey was performed using NaI detectors with a single channel analyser set to this energy range. MicroShield® and survey instrument calibration data were used to correlate gamma count rate to ^{234,235,238}U and decay product concentrations. Scanning measurements are shown in Figure 1.

Figure 1. Track of survey unit scans. Count rates as related to the mean are listed in the Legend.

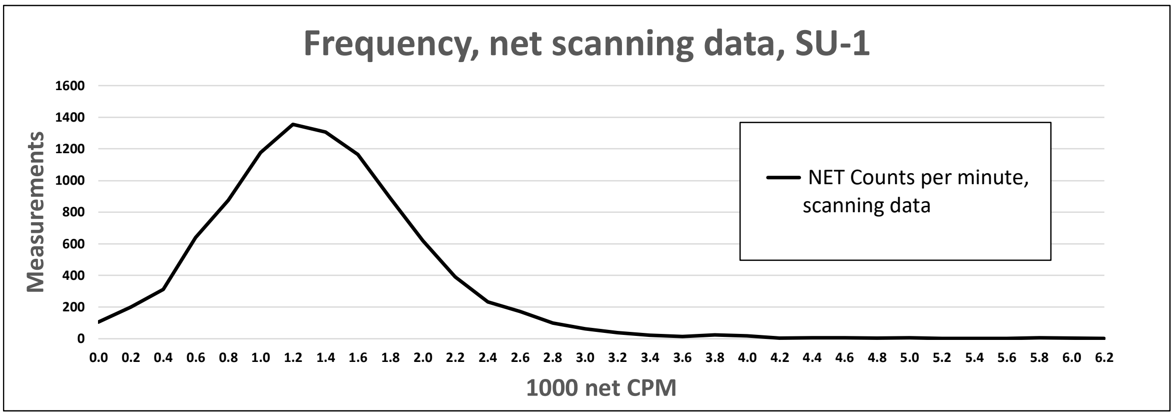

Figure 2. Scanning result in counts per minute for SU-1 vs number of measurements.

The frequencies of scanning measurements are shown in Figure 2. The count rate was measured using a Ludlum® Model 44-10 5.08 x 5.08 cm NaI detector with a Ludlum® Model 2221 operated as a single channel analyzer.

Direct measurements

ICP-MS analysis were used to quantify the radioactive content of systematic surface soil samples. The number of soil sample locations, N, were based on Section 5.5.2.2 and equation 5-1 of MARSSIM [7] resulting in 16 samples collected from the survey unit and 16 samples collected from the reference background area. Sample locations were determined using a triangular grid pattern and a random start.

Analysis

Four parameters were incorporated into the simulations of the scanning measurements including their uncertainties. They are the survey system count rates, the activity fraction of each uranium isotope in each count rate measurement, the efficiency of the survey instrument, and the clearance concentration (CL_i) from the scenarios. The CL_i values are, respectively for each radionuclide, in units of Sv per year divided by Bq per gram. CL_i values including the cumulative uncertainties were modeled for a resident farmer scenario using RESRAD-ONSITE [5]. For the simulations of sampling data, two parameters with their corresponding known uncertainty were used, namely, the nuclide concentration from laboratory analysis and CL_i from the scenarios.

The SOF presented in *Equation 1*, also known as the unity rule, was used to determine compliance with radioactivity criteria for clearance. The SOF is a sum of ratios. The numerators are the measured activity concentrations of each radionuclide (m_i). The denominators are produced by the scenario model, which generates the CL_i, i = 1….n. Thus, the total dose allowed for clearance is required to satisfy the SOF inequality. That is:

$$\sum_{i=1}^{n} \frac{m_i}{CL_i} \leq 1$$

Equation 1. Sum of fractions, SOF

A series of Monte Carlo simulations were performed to obtain a preliminary estimate on the distribution of the SOF as a function of the number of simulations using a method described in (Meck and Jiselmark 2021) [1]. A total of 10,000 Monte Carlo simulations were performed for the discrete sampling measurements and 9784 Monte Carlo simulations for the scanning measurements.

By Monte Carlo simulating the Sum of Fractions with all known uncertainties, including the uncertainties of the CLi values, for all integrated areas, the 95th percentile of SOF could be calculated for all scenarios that could affect clearance decision. In our case external radiation for t = 0 years and drinking water from a well at t = 1,000 years.

RESULT

We modelled annual doses to a resident gardener for the following years: 0, 3, 10, 30, 100, 300, 1,000, 3,000, and 10,000. No scenarios dominating the doses have been assumed to exist for times larger than 10,000 years. Figure 3 provides the 95th percentile of SOF shown based on scanning data for the whole SU-1 and including uncertainties of the nuclide specific clearance limit (CL_i).

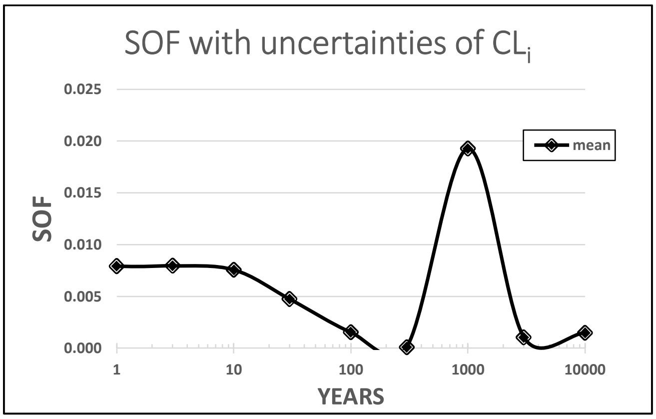

Figure 3. Dose varies with time

As shown in Figure 3, the maximum value for SOF varies with time and scenario. Two scenarios are depicted in Figure 3, because the maximum dose before approximately 300 years is from the external pathway. We found that after approximately 300 years, ingestion of water from an onsite well would result in the greatest dose, and thus, the greatest SOF. The maximum modeled SOF from the whole SU-1 is at 1,000 years from the present, at 0.019 with a standard deviation of 0.0094.
Table 1, shows the effects of time on dose from the greatest exposure pathway for the ROC.

Table 1. Greatest dose scenarios and nuclides

Percentage of Total Effective Dose Equivalent (TEDE) Per Nuclide								
	Years After Measurements							
	0		100		300		1,000	
	Exposure Pathway & Dose		Exposure Pathway & Dose		Exposure Pathway & Dose		Exposure Pathway & Dose	
Nuclide	External	TEDE	External	TEDE	External	TEDE	Water ingestion	TEDE
^{234}U	0.30	3.30	0.63	3.7	15.7	18.9	60.9	61.0
^{235}U	22.0	22.1	21.9	22.0	14.6	18.6	3.77	3.77
^{238}U	72.8	74.6	72.1	73.9	47.7	48.8	35.2	35.2
^{230}Th	<0.1	<0.1	0.42	0.46	12.5	13.5	<0.1	<0.1

Figure 1, shows that the maximum contaminated spot in SU-1 is located alongside the southwest border of SU-1. The external dose as a function of contaminated soil area was calculated using MicroShield® [6] and is provided in Table 2. SOF for external dose is calculated using the mean external dose within a defined surface area. If the full SU-1 would have been used the mean would have been 0.08 as shown in Figure 3. By using a more contaminated but smaller area for calculating the external dose, a more accurate mean can be calculated for the external dose scenario. As shown in Table 2, eighty percent of the external dose is received from the closest area of 70 m^2 with the contaminants of 2.7 percent enrichment uranium in the top soil. This integrated area was chosen based on engineering judgment of the likely movement of a person and the small incremental increase in dose with increasing areas.

Table 2. External dose at year zero from 2.7 percent enriched uranium to a receptor in the center of an area[1]

AREA (m^2)	20	50	60	70	80	90	100	110	200	1813
RADIUS (m)	2.52	3.99	4.37	4.72	5.05	5.35	5.64	5.92	7.98	24.02
NORMALIZED DOSE	0.61	0.77	0.79	0.80	0.82	0.83	0.85	0.86	0.91	1.00

Using the measurements within a radius of 4.7 m from the maximum contaminated spot in SU-1 located alongside the southwest border of SU-1 as shown in Figure 1, gives a circular area of 70 m^2. SOF for that location is shown in Figure 4.

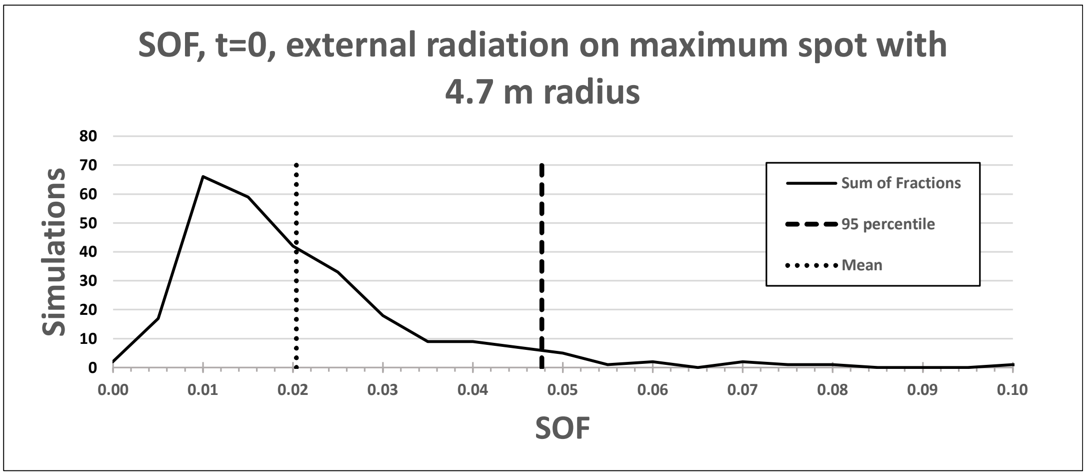

Figure 4. SOF for external radiation from maximum contaminated spot in SU-1, CLi for t=0, scanning data

As shown in Figure 4, SOF for the highly unlikely scenario that the dose receptor spends all their outside time at the maximum spot for a whole year is with 95 percent confidence less than 0.05 including the uncertainty of the action levels. The mean SOF for this scenario is 0.02.

As shown in Figure 3, the maximum yearly dose corresponding to the contaminants at the whole SU-1 is at t = 1,000 years, and it is dependent on people drinking contaminated groundwater. Ground water is modelled to have been percolated from the SU-1 surface to the aquifer and drunk undiluted from the aquifer. SOFs for this scenario is shown for both 9784 scanning measurements and for 16 sampling measurements in Figure 5.

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[1] Soil uniformly contaminated to a depth of 15 cm with 234U at 0.0738 Bq/g, 235U at 0.0030 Bq/g and 238U at 0.0232 Bq/g.

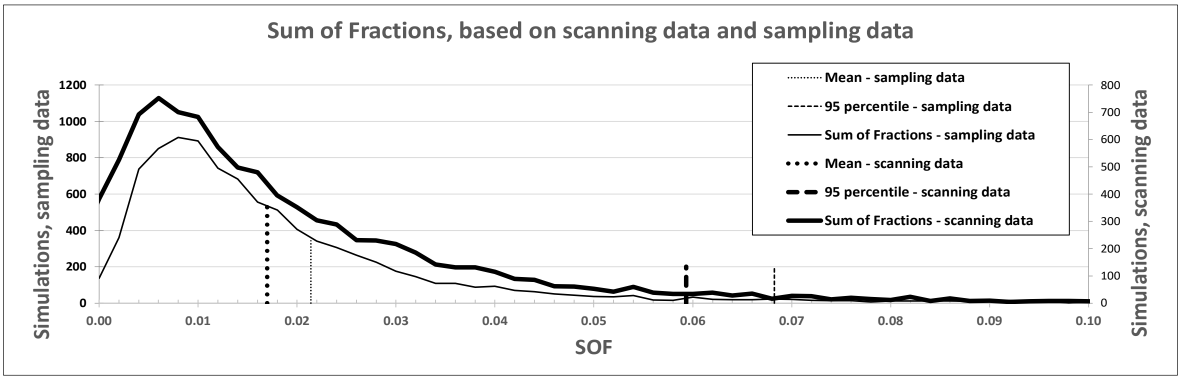

Figure 5. Sum of Fraction for dose from a well at 1,000 years based on scanning data and sampling data

Note that the 95th percentile in Figure 4 are slightly lower than in Figure 5. Since no person will spend their full outside time at the maximum location for a whole year, makes yearly doses from drinking contaminated water our dominating scenario.

It is very clear that both the mean and the SOF_{95} is significantly less than the criterion of 1.0. As one can predict, simulations that include uncertainties have greater SOFs than those that don't. Figure 6, shows the modeled dose for SU-1 at 1,000 years after the measurements, with and without the uncertainty of the CL_i values.

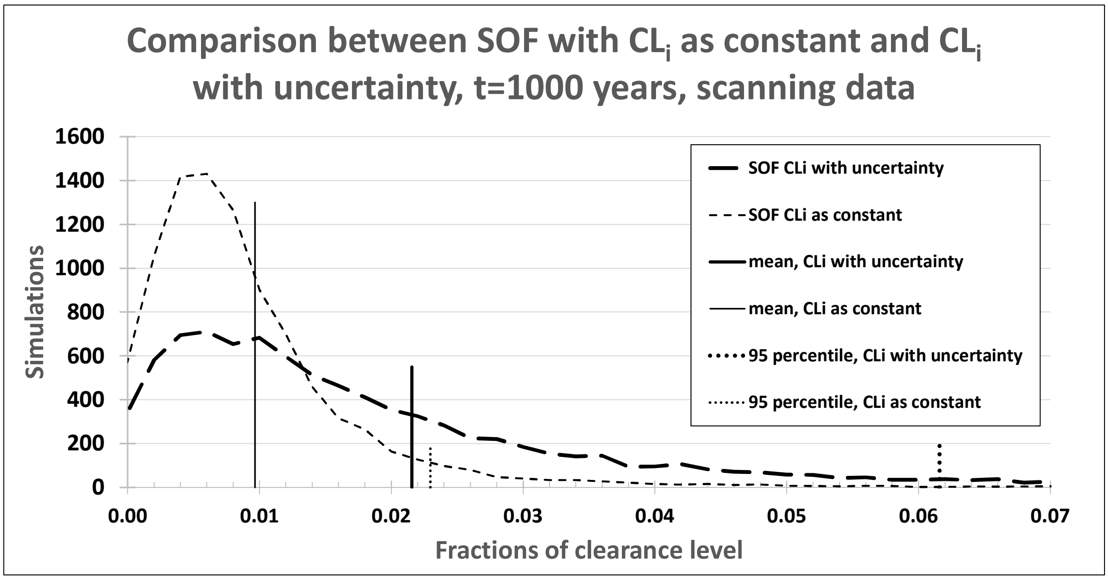

Figure 6. Comparison of dose distributions with and without uncertainties of CLi for T=1,000 years.

As shown in Figure 6, the mean goes from 0.01 to 0.022 in this simulation when the uncertainty of CL_i is included in the calculations. Given a more contaminated site this could have been significant from a clearance perspective.

It is possible to compare the effect of reducing the standard deviation of different parameters. For example, the field detector efficiency in CPM per concentration of nuclides have been measured but with a relatively large standard deviation. We have calculated the impact of reducing the standard deviation for the detector efficiency by half given different randomly selected measurements, the result is shown in Figure 7.

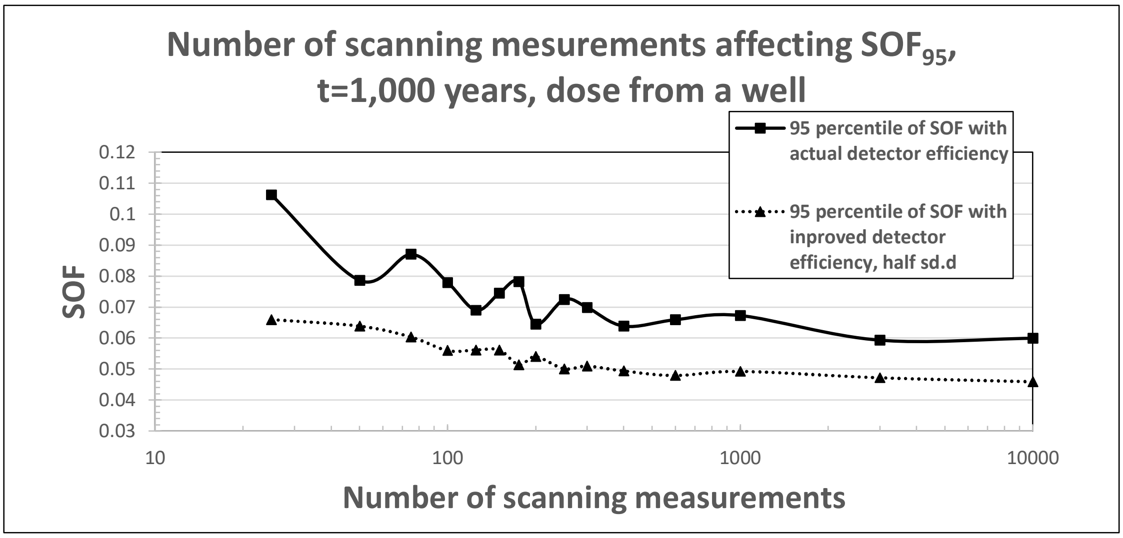

Figure 7. Comparison between the effect of adding more NaI measurements at the surface of the survey unit to reducing the standard deviation of the detector efficiency by half.

Figure 7 shows that given 25 field measurements, the clearance project would gain the same in reducing the standard deviation of the detector efficiency by half than performing about 500 more surface measurements. The 95th percentile of SOF is reduced from 0.106 down to 0.066 when the standard deviation of the detector efficiency is reduced by half, which is the same as adding about 500 more field measurements. Performing 10,000 instead of 1,000 scanning measurements have not significantly improved the 95^{th} percentile of SOF. In Figure 8 are the SOFs shown for scanning data, comparing N = 10,000 and N = 100 randomly selected data.

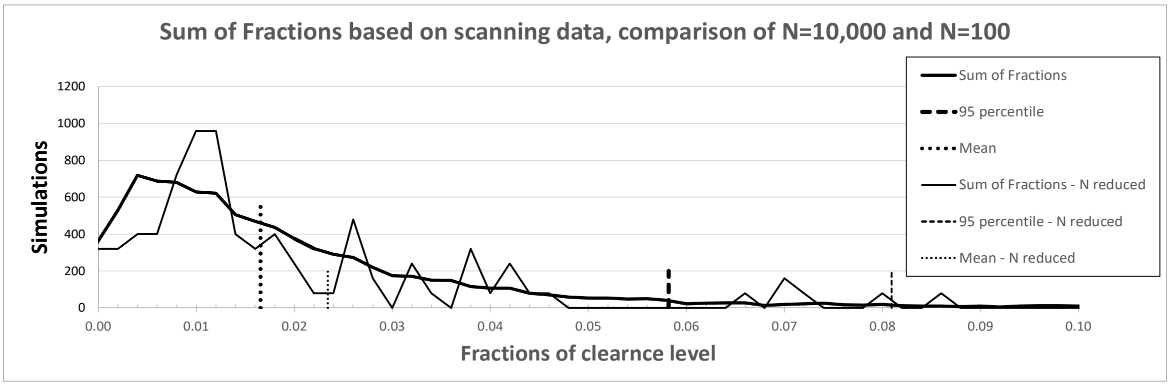

Figure 8. Sum of fractions using scanning data, comparison between N=10,000 and N=100 scanning measurements.

As shown in Figure 5, Clearance can be proven using different measurements of the same contaminants, using MCSOF for about 10,000 scanning data is compared to using MCSOF for 16 sampling data. To even out the sampling curve, all known uncertainties have been handled with 10,000 Monte Carlo calculations.

As shown in Figure 5 and Figure 8, clearance is met using survey and discrete measurements for SU-1. Scanning with a NaI detector with N = 10,000 shows $SOF_{95} = 0.06$. Scanning with a NaI detector with N = 100 shows $SOF_{95} = 0.08$. Laboratory analysis of N = 16 samples show $SOF_{95} = 0.07$.

DISCUSSION

Unrestricted clearance requires using site specific CL_is and measurements to generate a valid safety case for the site with no regulatory radiological restrictions in future uses. By using MCSOF for this work, one could handle the uncertainties in a non-conservative way. We have used RESRAD-ONSITE to generate CL_is based on site-specific information. For future work we recommend that the site-specific parameters be generated using the method described in reference [8] for biosphere systems. As described in ICRP publication 82 [3] quantification of the uncertainties of the annual doses should be an integral part of the dose estimations and should be described with a curve.

With MCSOF, it is simpler to estimate the mean annual dose in the critical group than an identified maximally exposed individual as discussed in publication 82 [3]. Estimating the maximal dose to an individual in the critical group without handling the uncertainties will generate an unrealisticly conservative dose estimation and therefore also higher costs for unnecessary remediation. Here, the SOF_{95} can represent a reasonable estimation for the high doses and are generated with no additional effort.

The restrictions for maximum dose to a person in a critical group is recommended by IAEA to be the lowest of the dose restrictions to the public during the operation phase or 300 µSv per year. Showing that SOF_{95} is below these two restrictions ensures clearance. More remediation is required if reasonable down to the order of 10 µSv per year [9]. Showing that SOF_{95} is below 10 µSv per year allows optimization of costs for the clearance project and can at the same time represent a value for the uncertainty for the average dose for a person in the critical group. We have used the clearance limit of 10 µSv per year in this work.

ICRP discuss in their publication 82 that radioactive residues are usually unevenly distributed, creating situations of heterogeneous prolonged exposure [3]. And these need to be addressed on a case-by-case basis by making realistic assumptions about the pattern of people's exposure. The analysis of integrated areas for different dose scenarios handles this issue as shown in this paper.

The clearance level is where the dose is considered insignificant (below 10 µSv annually). When planning the remediation and clearance measurement campaigns for another and more contaminated site, many aspects can be addressed. By using MCSOF, it is possible to plan the work using economic factors. It is also possible to trade more remediation to fewer measurements. By remediating more, the mean of the SOF curve will be far from 1 which allows for a wider curve, still proving that $SOF_{95} < 1$. There are more parameters to the SOF equation than field measurements and by using MCSOF it is possible to compare the effect of putting more funds in field measurements, detector efficiency measurements or parameters affecting the uncertainty of the action levels (CL_is). It is also possible to compare the effect of using more and cheaper measurements to fewer and more precise measurements, as shown in Figure 5.

For sites with relatively less expensive waste routes for soils, and contaminants that require costly measurements, it may be acceptable to conduct more remediation and perform fewer field measurements. A cleaner site is beneficial for everybody; the public will have a cleaner area; the regulatory authority will have easier clearance decisions showing a SOF_{95} far below 1; and all known uncertainties have been addressed. In addition, the operator can plan the work using economic factors and balance performing more remediation with fewer measurements, while still demonstrating compliance to the clearance regulations.

Nearly all demonstrations of compliance with clearance criteria currently are based on nonparametric statistics. As such, the analysis is for the median dose to an individual in the critical group. They are based on an assumed statistical distribution and states the probability of the median but do not account for all known uncertainties. In contrast, regulatory authorities' base compliance on the dose to the average member of the critical group—not the median member of the critical group. Our method quantifies all known uncertainties with Monte Carlo simulations. This accounting of uncertainties is required as noted in the assertion of at least eight international authorities, including the International Organization for Standardization and the International Union of Pure and Applied Chemistry [10]. They state that a measurement without its stated uncertainties is incomplete, not technically sound, and may not be considered defensible. Our MCSOF method provides the highly accurate quantified probability and uncertainty of compliance with the clearance criterion. Therefore, it improves verification of clearance. In this work we demonstrate the application of MCSOF method to measurement data from a real site as a "Proof of Concept." The evaluation of the mean dose, and quantified uncertainty of all known parameters are technically sound reasons for demonstration of compliance with clearance criteria.

Clearance is the termination of regulatory control of radioactivity on and in land, buildings, materials, equipment and liquids. Clearance is usually based on the dose to the average individual of the critical group for a limiting scenario of that group. Therefore, the mean should be compared to the clearance level. If the mean SOF is less than, or equal to, 1 a site can be cleared.

In nearly all cases, measurements and calculations are the basis for demonstrating that clearance criteria have been met. Consequently, that demonstration is based on the statistics of multiple measurements. There is usually no reason to expect that the distribution of the measurements exactly fits a familiar one, such as a Poisson, Gaussian, log-normal, or uniform distribution.

This being the case, default nonparametric analyses are widely used to determine compliance with the clearance criterion [7] [11]. As the radionuclides of concern at SU-1 are naturally occurring radionuclides, MARSSIM [7] requires the Wilcoxon Rank Sum (WRS) test be used to determine compliance with the clearance criterion. Shortcomings of the WRS test is that it requires that the number of samples collected from the survey unit and the reference background area be equal, the variance of the radionuclide concentrations in the samples collected from the survey unit and the reference background area be equal, and the WRS test evaluate the median and not the mean [12]. Further, all known uncertainties of the input parameters, such as measurements of the activity percentage of each radionuclide, are often not considered. As a result, conservative estimates are assumed and used to ensure that clearance criteria are met. Such assumptions are not only less accurate but can lead to costly clean up implementation. This work demonstrates that the actual data can be used to increase accuracy and potentially decrease cost.

Our method used the SOF rule and quantifies the known uncertainties. Stating the uncertainty is required to make the SOF value technically sound. At least eight international scientific and technical organizations state that a measurement without its stated uncertainties is incomplete [10]. That is, measurements stated without their uncertainty are not technically sound and are not defensible [13].

The uncertainty provides the answer to how well do we know the SOF is less than or equal to one. That answer is of interest to the regulatory authority for ensuring that clearance criteria are met. The method described in Meck and Jiselmark [1]. shows that Monte-Carlo simulation of the SOF and its quantified uncertainty, can improve verification of clearance. MCSOF is an improvement because all measurements actually create the distribution—no statistical analysis is needed since the entire distribution is used. Consequently, MCSOF results in increased accuracy and reduces conservative estimates of dose. In this present work we have demonstrated MCSOF with real data from a remediation and clearance project for a site in the US. We have demonstrated that MCSOF can be applied even to scanning low energy photon emissions. It can also apply to discrete samples measurements as shown in Figure 5. Since discrete samples usually require laboratory analysis, they can cost significantly more than scanning measurements but are on the other hand more precise. This indicates that it is possible to choose how to measure and to use MCSOF to plan and cost optimize a clearance project. This is under evaluation and will be described in a future publication.

Each MCSOF simulation includes in its calculation all known uncertainties for the specific dose scenario. The scenario that results in the greatest estimated dose to the average member of the critical group was found by comparing the SOFs of probable scenarios. RESRAD-ONSITE was used to calculate the concentration of a nuclide that would result in the clearance criteria for dose in the scenario that was applied. We have calculated the doses from year zero to 10,000 years post closure based on scanning data and ICP-MS analysis of soil samples. The maximum dose, and thus the maximum SOF, from the whole SU-1 is predicted to be received through drinking ground water from a down-gradient well at 1,000 years after the measurements were taken. This result is shown in Figure 3, and Table 1. A detailed examination of the application and the uncertainties of RESRAD-ONSITE output is the subject of work that is in progress.

With MCSOF it is easy to plot the dose for the maximum dose scenario including uncertainties and presents it in a clear picture. Complete accounts of known uncertainties are included for technically sound verifications that clearance criteria have been met. The graphic visualization of the SOF or the dose enables clear communication with stake holders such as the regulatory authority and the public representatives.

CONCLUSION

MCSOF uses the actual measurements and are not dependent on fitting a known distribution. We have presented a method, MCSOF, that is a more practical and accurate approach to decision-making at all sites including those with a low dose. The method likely is simpler and more understandable than present methods for the public and for decision-makers. The inclusion of all measurements, rather than an assumed or a fitted distribution, is more accurate and not conservative. It thus improves verification of compliance with clearance dose requirements. Consistent with regulatory requirements to evaluate the average member of the critical group, the MCSOF method quantifies the mean SOF and quantiatively incorporates all known uncertainties. In contrast, non-parametric analyses frequently used are based on the median. As a proof of concept, we demonstrated that the application of MCSOF with all measurement data from a real site can be performed readily.

MCSOF handles variation within the survey unit and can be used for planning the remediation and clearance project. MCSOF is a great tool for comparing how and what to measure. For sites with relatively inexpensive waste routes for slightly contaminated soil, MCSOF can be used to plan the remediation and trade more remediation to fewer measurements. In the dose region below 10 μSv per year it is possible to use MCSOF for cost optimization of the whole remediation and clearance project. MCSOF can also be used for analyzing if a previous performed clearance project has been performed in an economical efficient way.

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