Radioactive Waste Management Associates

Memo

To: Gary Abraham

From: Marvin Resnikoff

Date: March 21, 2013

Re: Fac Pond 8 Sampling

I. Summary

This report reviews several issues regarding the radioactive characterization and remediation of Fac Pond 8. Constructed in 1973, long past waste burial operations at the LOOW site, Fac Pond 8 was used for storage of treated wastewater prior to discharge to the Niagara River. It is located near the southern border of the CWM property, adjacent to RMU1.

The issues addressed in this report are:

Sufficiency of Sampling. Has LATA/EnSol taken a sufficient number of samples in Fac Pond 8 to confidently determine the concentration of radium-226? In particular, has LATA/EnSol correctly applied the interagency statistical methodology, Multi-Agency Radiation Survey and Sampling Manual[1] (MARSSIM,) for sampling Fac Pond 8, as they claim?

Applicable Modeling Assumptions. Based on the sampling history of Fac Pond 8, do we have confidence that Fac Pond 8 has been decontaminated to applicable regulatory standards? This question is tied to the likely future use and clean-up criteria for the LOOW site. Will the future use be industrial, agricultural or residential?

Applicable Cleanup Standards. What is the cleanup standard being used by LATA - the Nuclear Regulatory Commission (NRC) standard for a decommissioned site (25 mrem/yr or 100 mrem/yr), the State guidance (10 mr/y), or another standard?

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1 (MARSSIM, 2000)

As discussed below in Section III, the MARSSIM governs the investigation of radiologically contaminated sites. According to MARSSIM, the first step is a historical review of the site to determine whether the site is likely to be contaminated. A site that has been contaminated would require more intensive sampling.

A 1971 – 1972 AEC survey[2] identified surface contamination near the southwest corner of Area C, where Fac Pond 8 is located. Oak Ridge Associated Universities (ORAU) stated, "This finding suggests possible storage or shallow burial of contaminated material may have occurred." No records show how Fac Pond 8 was constructed, particularly the berms surrounding the 500yd by 500yd former pond. It is not inconceivable that the berms were constructed with a bulldozer leveling the flat center of the pond, thereby pushing contaminated soil into the berms. As we show, a foot of soil attenuates gamma radiation in the U-238, Th-232 decay chains by 98%. Accordingly, as we show, a surface scan with radiation detectors could not measure subsurface contamination. A careful review of the history of Area C should have led LATA/EnSol to conduct push probes of the entire site. By the number of samples taken and the survey methodology employed, the surveys conducted done by LATA/URS[3], published April 2012, could not detect subsurface radioactive contamination. It is important to stress that EnSol, which conducted the survey that provides the basis for the LATA/URS survey report, is not a licensed contractor.

The surprise discovery of contamination in Survey Unit (SU) 9 after the LATA Completion Report[4] showed contamination in only SU 6 and SU 10, throws into question the survey results for the entire FP 8. For sampling purposes, FacPond8 was broken into 12 sections. See Figure 1. Based on EnSol's surface gamma survey and soil samples of Fac Pond 8, two of the sections, 6 and 10, which are adjacent, had Ra-226 concentrations above background. Concentrations of U-238, U-235, U-234, Th-232 and Th-228 in section 10 were essentially at background; one can show that with high statistical confidence. Th-230 concentrations were slightly elevated.

According to EnSol, SU 9 was at background concentrations. Background is taken as the average of the other ten sections of FacPond8. In examining SU 10 more closely, LATA showed that one location, with three samples at differing depths, had very high Ra-226 concentrations. As a result, the average Ra-226 concentrations in section 10 were elevated, and the statistical standard deviation was very high. Under these conditions, if this were the Final Site Survey, MARSSIM would require a much larger number of samples to be taken in a planned array that covers the contaminated area, to be confident that one has a reliable average Ra-226 concentration. This was not done. Instead, LATA continued to remove all hot spots they could identify with surface gamma readings, and then applied

[2] (ORAU, 1984)
[3] (LATA, 2012a)
[4] (LATA, 2012b)

MARSSIM to the partially cleaned up surface samples. As discussed in Section III below, this is contrary to MARSSIM sampling guidance.

In a letter to CWM[5], The Department of Health stated that the "site-wide gamma walkover survey…is not a final status survey, as all of the components of MARSSIM (as well as subsurface investigations) will not be implemented." Despite this admonition, the 2012 reports for SU 6 and 10[6], and SU 1-5, 7, 8 and 11, 12[7] are titled "Final Status Surveys." However, MARSSIM procedures for final status surveys were not followed.

In July 2012, LATA conducted an additional survey of SU 9 of Fac Pond 8. In the EnSol 2010 survey[8],. this was a section that was previously considered decontaminated. But a more intense examination showed that SU 9 was contaminated, by a vein of contamination greater than 3 feet below the surface. This finding is deeply disturbing because this survey unit was considered clean and raises the issue of EnSol's competence. Push probes by LATA found contamination below the surface, with Ra-226 concentrations very high, 191 pCi/g. The sum of fractions calculation (discussed later) shows this area remains contaminated after remediation.

LATA's methodology and results for SU 9 raise the basic question whether or not contamination remains at other SU's within Fac Pond 8. Surface gamma surveys cannot identify contamination that resides one to three feet below the surface. Only a carefully plotted array of locations for sampling with push probes, as laid out in MARSSIM, will answer the question of whether the site has been decontaminated to regulatory standards.

Are the Ra-226 concentrations in section 9, a health and safety concern? In our opinion, they are and further remediation is required. In order to answer the question of radiation dose, and to determine the number of required samples according to MARSSIM, one has to have an exposure model. Under the Remedial Action Plan (RAP), LATA assumes contamination must be removed such that the radioactive concentrations of Ra-226, thorium-230 and total uranium have concentrations less than 5 pCi/g, 5 pCi/g and 60 pCi/g, respectively. SU 9 does not meet these criteria. Another model customarily employed by federal agencies is the farmer resident model, where a farmer grows crops, has cows and drinks water from the site. SU9 does not meet this model either. Further remediation is required.

In the farmer resident modeling, one assumes a resident builds a home in SU 9, thereby unearthing soil and mixing it homogeneously on the property; this is the excavation model[9] used at NRC sites[10]. This is a reasonable model for the CWM

[5] (DOH, 2005)
[6] (LATA, 2012c)
[7] (LATA, 2012a)
[8] (EnSol, 2010)
[9] (NRC, 2006)
[10] (Westinghouse, 2005)

site 100 years from now, since the area is basically agricultural and one cannot rely on today's institutions 100 years into the future. The consistently stated policy of Niagara County for over a decade is to return the site to residential use. As discussed later, using default parameters, the resident farmer model estimates a radiation dose greater than 25 mrem/y, that is, higher than the allowed regulatory radiation dose following decommissioning, 25 mrem/y (Federal) or 10 mrem/y (NY)[11]. In contrast, though it employs DEC recommended concentrations for soil, LATA[12] also develops radiation dose estimates based on working in FAC Pond 8 for 20 weeks, preparing the site for RMU 2.

This report is not going to fully address how Fac Pond 8 became contaminated. The LATA study of Survey Unit 9 shows a dark vein of contamination 7' to 12' below the berm, with pieces of wood and metal. Since pieces of wood and metal cannot migrate, the obvious conclusion is that during construction of Fac Pond 8, radioactive waste materials were either brought in, or the area was indeed used for waste storage. However, the remainder of this memo is limited to addressing a scientifically valid and full remediation[13].

II. History of Fac Pond 8 Radiological Characterization

EnSol Characterization

Fac Pond 8 is located near the southern border of the CWM property, adjacent to RMU-1. It was constructed in 1973, long past waste burial operations at the LOOW site. From the top of the side berms, the pond is 500' by 500', with an average depth of 22'. The pond was drained prior to EnSol's surface scan and sampling. In 2010, EnSol conducted the first detailed characterization of Fac Pond 8, including a survey scan and sample collection[14]. This followed initial radiological surveys by URS in 2005 and 2007[15]. For characterization, EnSol divided Fac Pond 8 into 12 survey units, four survey units (9-12) for the side berms, and eight survey units (1-8) for the floor, as seen in Fig. 1.

Except for survey unit 6, 15 randomly selected locations were sampled for soil at varying depths and laboratory tested for U, Th and Ra. In survey unit 6, 30 samples were taken. Two survey units, 6 and 10, had gamma measurements greater than 16,000 cpm, the investigation level. In survey unit 9, the northern berm, no surface gamma radiation values exceeded the investigation level of 16,000 cpm. One location in survey unit 10, the eastern berm, exceeded 16,000 cpm, with radium concentrations of 2550 pCi/g, far above the decon criteria of 5 pCi/g. This "seam" of contaminated soil was removed.

[11] (NYSDEC, 1993)
[12] (LATA, 2011a)
[13] *Ibid*
[14] (EnSol, 2010)
[15] *Ibid*, p. 1-2.

In our opinion, EnSol's surveys were unreliable. EnSol stated that no surface gamma radiation values exceeded 16,000 counts per minute. "For survey units 9, 11 and 12 on the interior sideslopes of the Fac Pond berms none of the surface gamma radiation values exceeded 16,000 counts per minute (cpm)."[16] But, in a subsequent survey by LATA[17], seen in Fig. 4, EnSol missed 50 surface hotspots, where some gamma radiation values ranged between 30,000 and 120,000+ cpm. EnSol's subsurface sampling also failed to detect 66 tons of subsurface SU 9 contamination. According to EnSol, SU 9 should have been free of contamination.

While LATA claimed that testing by EnSol followed MARSSIM guidance (discussed later), this is not correct. Once it is known that an area is contaminated, called category 1 in MARSSIM, additional samples must be taken in an array that adequately covers the survey units, as seen in Figure 2a. Instead, EnSol sampled each survey unit in a somewhat random array. Each location where sampling indicated radioactive concentrations were higher than background was removed. While this method is somewhat useful, it does not increase our confidence that all locations above background have been found, particularly for subsurface contamination. A more systematic approach under MARSSIM is required.

LATA Remedial Action Plan

In June 2011, LATA developed a Remedial Action Plan with the following objectives: a public cleanup goal of 5 pCi/g for total Ra and a whole body exposure dose limit of 10 mrem/yr[18]. The MARSSIM methodology to be employed for sampling in LATA's remedial action plan, incorporated these data quality objectives (DQO).

However, instead of decommissioning model that assumed a resident living on the remediated site, LATA calculated the likely radiation dose to construction workers in the Fac Pond 8 area. The analysis assumed the number of hours a worker remained in the area and direct gamma and perhaps incidental ingestion doses. The dose was incorrectly compared to the regulatory standard for an operating nuclear facility, 100 mrem/y, rather than the allowable dose from a decommissioned facility[19], 10 mrem/y. For purposes of remediation, LATA accepted DEC's concentration guidance 5/5/60 pCi/g for Ra-226, Th-230 and total U. We calculate the dose for a decommissioned Fac Pond 8 later in this report, assuming instead a full-time resident, which is a standard conservative decommissioning model. Institutional structures are not assumed to be present after 100 years.[20]

LATA Final Status Survey Report, Survey Units 6 and 10 and Completion Report

[16] *Ibid*, p. 1.
[17] (LATA, 2012b)
[18] (NYSDEC, 1993)
[19] *Ibid.*
[20] 10 CFR 61.59

In April 2012, LATA reported sampling in SU 6, 9 and 10. Areas 6 and 10 had been previously surveyed by EnSol, and supposedly remediated. Yet the walkover survey identified small patches of slightly elevated radioactivity. The April 2012 report noted "an anomalous vein of radioactive material…in the center of the berm approximately 3 feet below ground surface." The report does not further consider the implication of this finding, that a surface gamma survey with a Ludlum 2x2 NaI detector would not find this "anomalous vein," it could only be detected with deep probes and soil sampling.

While the Final Site Survey (FSS) states that Fac Pond 8 was categorized as class 1 under MARSSIM by EnSol and LATA, sufficient below surface samples were never taken, as we discuss later. This vein was not remediated and "will be addressed in a future remedial effort." [21]

LATA Completion Report, Survey Unit 9

As a follow-up to the Final Status Report and the Completion Report, LATA collected and analyzed 21 below surface samples in survey unit 9. Survey Unit 9 is the northern berm of Fac Pond 8, closest to RMU-1. Twelve of 20 samples exceeded cleanup standards, 5 pCi/g for Ra-226 and Th-230, using the sum of fractions rule (discussed in Section IV). This contamination was at depths below 3 feet; the final site survey found contamination at 7 to 12 feet below the surface of the berm, in a somewhat random sampling of SU 9, as seen in Fig. 2b, rather than the more systematic sampling array required under MARSSIM (Figure 2a) discussed below. This survey identified, but did not remediate, the remaining contamination, which is above regulatory limits. This vein of "anomalous material", darker than surrounding soil, was extensive and contained wood and metal debris. In the absence of systematic subsurface sampling, there is little basis for concluding that this vein of contamination is anomalous. It is unlikely that wood and metal migrated; it is more likely that, despite the lack of a clear historical record, either this area was used as a waste disposal location, or waste materials were brought in during construction of the berm of Fac Pond 8.

LATA claims that site remediation work was done under MARSSIM guidance. So we next briefly discuss MARSSIM and apply the guidance to the remediation work done so far.

III. MARSSIM Sampling Guidance

MARSSIM, the Multi Agency Radiation Survey and Site Investigation Manual, is a "nationally consistent approach to conducting radiation surveys and investigations at potentially contaminated sites."[22] It is an approach developed by the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC) and the Department of Energy.

[21] (LATA, 2012b)
[22] (MARSSIM, 2000), p. 1-1.

MARSSIM prescribes a graded approach to classifying areas to be decommissioned, in order to place the greatest effort on areas likely to have contamination[23]. Class 1 areas are those that have a potential for radioactive contamination. Class 2 areas are those that have a potential for radioactive contamination, but are not expected to exceed the DCGL. Class 3 areas are those that are not expected to contain any residual radioactivity or "are expected to contain levels of residual radioactivity at a small fraction of the DCGL."[24] As we discuss later, clearly survey units 6 and 10 fit into class 1 under MARSSIM definitions.

In its methodology, MARSSIM distinguishes between areas that contain radionuclides that are present in background and those that do not. An area that contains radionuclides in background media requires a greater sampling effort than those areas that do not. In the case of Fac Pond 8, radionuclides such as radium-226, thorium-232, thorium-230 and uranium-238 are present in background media. As we will see later, radium-226 is of greatest concern.

MARSSIM starts with a historical site assessment, a collection of existing information that describes a site's complete history. Fac Pond 8, within DOE vicinity property C, apparently was used for waste storage, at one time. Surface ground surveys by URS and EnSol found gamma levels above background. According to MARSSIM, Fac Pond 8 then fit within class 1, requiring a greater survey effort. The difficulty here is that in parts of Fac Pond 8 the contamination lay in a seam below the surface and therefore was difficult to detect. As we discuss later, the top soil layer shielded the gamma radioactivity emitted from the seam below the surface.

We focus here on whether CWM contractors have properly employed MARSSIM, as they claim, and specifically, whether a sufficient number of data points (sampling locations) in a proper array have been selected. In short, can one have statistical confidence that average values for Ra-226 and other contaminants have been determined? Chapter 5 of MARSSIM lays out the procedures required to answer this question. In general, an initial survey is followed by remediation of a site, to levels below the data quality objectives (DQO). LATA has chosen DQO to be Ra-226 5 pCi/g, Th-230 5 pCi/g and total U 60 pCi/g. In our calculation, differing from LATA's, we choose the more restrictive DQO adopted by the NRC limit[25], 25 mrem/y, or the State limit[26], 10 mrem/y.

In order to translate these radiation dose limits to concentration limits for specific radionuclides present in Fac Pond 8, one needs a radiation model. The standard model chosen for a decommissioned site, is either a resident model or a farmer resident model, where an adult constructs a home and lives on the contaminated

[23] (MARSSIM, 2000), p. 2-4
[24] (MARSSIM, 2000), p. 2-5
[25] (NRC, 2012)
[26] (NYSDEC, 1993)

site. The model choice assumes that in the long-term, greater than 100 years, institutional structures cannot be relied on to control use of a site.

As seen in Figure 3, under MARSSIM, modeling of the site and the Derived Concentration Guidance Levels (DCGL) are determined separately. The DCGL is the concentration of a radionuclide that yields a dose at the regulatory limit of 25 mrem/y. Though both surface and subsurface sampling is discussed[27], MARSSIM refers to NRC[28] and EPA[29] references for specific survey techniques. Given the DCGL's, MARSSIM uses statistical tests to determine the confidence in measured results. In particular, MARSSIM provides the number of survey measurements to ensure the average radium measurements are statistically reliable.

Following remediation, one performs a final status survey (FSS), with a sufficient number of samples to have confidence that the average radionuclide concentrations are below the DQO. Except for SU 9, LATA reports are titled "Final Status Surveys;" this is incorrect since a sufficient number of samples in a systematic array have not been taken.

For the FSS, MARSSIM employs a statistical test to determine whether one has confidence that the mean values of radionuclides are statistically representative, as discussed in Chapter 5 of MARSSIM. To do this, we need to set up statistical hypotheses, or allowable Type 1 (α) and Type 2 (β) decision errors. Type 1 errors are false positive errors. The percentile represented by the false positive error is $Z_{1-\alpha}$. The usual choice is $\alpha = 0.05$. Type 2 errors are false negative errors. The percentile represented by the false negative error is $Z_{1-\beta}$. The term (1-β) is the probability of rejecting the null hypothesis when it is false and is referred to as the power of the test. If β is too small, the number of measurements becomes too large. The usual choice is $\beta = 0.10$.

Two additional variables delta (Δ) and sigma (σ) are required by MARSSIM. Sigma is the standard deviation of the measured sample. Delta is called the shift, in MARSSIM-speak, and is the difference between the DCGL and the lower bound of measurements, which is usually taken to be ½* DCGL. Once one designates the type 1 and type 2 errors and calculates the ratio Δ/σ, MARSSIM will provide the recommended number of measurements to be taken.

IV. Application of MARSSIM to SU 9

We use SU 9 as an example of the application of MARSSIM and analyze whether LATA has correctly followed MARSSIM, as they claim.

After having discovered that SU 9 was contaminated, LATA used a push probe down to a 16 foot depth, discovering contamination below 3 feet. According to

[27] (MARSSIM, 2000), p. 5-8.
[28] (NRC, 1994)
[29] (EPA, 1993)

sampling in Appendix E, Ra-226 concentrations in this "anomalous vein" were 191 pCi/g. [30] Other radionuclides were also present.[31]. SU 9 was then decontaminated and a survey was taken. The results are shown in Table 1. Two values in LATA's Table 1 were in error and corrected.

To determine whether the survey unit has been remediated to either DEC's limits or the DCGL's determined by a dose model, one uses the sum of fractions rule.

$$\sum \left(C_i \ / DCGL_i \right) \le 1$$

where Ci is the average concentration of radionuclide i in the survey unit and DCGLi is the derived concentration of radionuclide i.

If the average radionuclide concentration for radionuclide i is greater than the $DCGL_i$, this means the concentration of radionuclide i exceeds the DEC limit, for Ra-226, exceeds 5 pCi/g. For several radionuclides, one must sum over all the ratios $C_i/DCGL_i$. As seen in Table 1, the sum of fractions is greater than one for 12 of 19 of the soil samples, using the DCGL's specified by DEC, 5, 5, and 60 pCi/g for Ra-226, Th-230 and total U, respectively. The average sum of fractions is also greater than one, implying that SU 9 requires further decontamination before Fac Pond 8 can be released.

We use a different method for calculating the DCGL's, since it is our opinion that 5 pCi/g for Th-230 has no factual basis and should be greater. We employ a model, labeled by the NRC and NRC licensees, the excavation model[32]. We assumed this radioactive contamination was excavated and spread on the surface one foot deep, with no cover, on a plot 50m x 60m (3000 m2); we also assumed a resident, who has a garden and works off-site, lives on the site. DCGL's are the soil concentration for each radionuclide of concern that yield a radiation dose at the NRC decommissioning limit, 25 mrem/yr. We used the RESRAD computer model[33] to determine the radiation dose via different pathways: direct gamma, food (garden) and water ingestion, incidental soil ingestion and inhalation. The DCGL's are shown in Table 2, and can be compared to DEC recommended DCGL's of 5/5/60. As seen, 13 of 19 soil samples have a sum of fractions greater than 1.

The calculated radiation dose, due to the remaining Ra-226, Ra-228, Th-230, total uranium and lead-210 is 44.7 mr/y, that is, greater than 25 mrem/y, the NRC regulatory limit. SU 9 should therefore be further remediated.

We also ran RESRAD with the same mix of radionuclides, but with a one foot cover, rather than no cover. The direct gamma dose for a one foot cover, is 2% of the case with no cover. This reflects the fact that one foot of soil cover blocks most

[30] (LATA, 2012d)
[31] *Ibid*.
[32] (NRC, 2006), App. J
[33] (ANL, 2000)

gamma radiation and confirms that a gamma survey to detect ground contamination, as LATA and EnSol did, will not detect MED contamination below the surface. The only means of detecting MED contamination below the surface is with push probes down to the underlying radioactive contamination. This should have been done in all SU's of Fac Pond 8. However, it should be noted, a one foot soil cover would not reduce the dose due to consuming vegetables and fruits from a garden since plant roots would still extend to the contaminated root zone.

The next question we addressed is – Based on the sampling data, did LATA take a sufficient number of samples in the final site survey, in an ordered array, as required under MARSSIM? That is, do we have confidence in the mean values for Ra-226 and other radionuclides calculated by LATA? As stated above, we choose $\alpha = 0.05$ and $\beta = 0.10$. For the decommissioning model we chose, the DCGL for Ra-226 is 3.16 pCi/g. From Table 1, the standard deviation is $\sigma = 3.374$. The ratio $\Delta/\sigma = 0.94$. For radionuclides that also appear in background media, we find, from MARSSIM Table 5.3, the number of samples N should be 62; half, 31, should be taken for background measurements and half should be taken in the contaminated region. Instead, LATA took 19 samples, an insufficient number according to MARSSIM. In addition, LATA relied on only one sample for background. Further, MARSSIM details a sampling configuration, shown in Figure 2a, in order to have confidence that the entire survey unit has been covered. The configuration chosen by LATA is shown in Figure 2b. Samples were taken essentially in a straight line, not as MARSSIM has recommended. We therefore cannot be certain that LATA has fully delineated all the subsurface contamination in SU 9.

Based on the results in SU 9, we conclude that a gamma survey of Fac Pond 8 carried out by EnSol and LATA cannot be effective in detecting subsurface contamination. In addition, Fac Pond 8 should be carefully mapped out according to MARSSIM, and push probes for radioactive contamination should be employed.

V. Appropriate Decommissioning Standard for Fac Pond 8

In order to evaluate the hazard of a radioactive contaminated site, we employ a model that represents the relationship of a resident to the site and the likely radiation dose a person would receive. This dose is then compared to the decommissioning standard adopted by the NRC or DOE or NYSDEC. The decommissioning standard set by the NRC is a whole body committed dose (TEDE) dose of 25 mrem/yr above background. NYSDEC has a more restrictive dose standard, 10 mrem/y above background.

We employ an excavation model for the contamination source. As seen in LATA measurements for SU 9, the "anomalous vein" of radioactive material is one foot thick, at various depths below the surface. The excavation model assumes this contaminated material is excavated, at an average concentration for each radionuclide for all the samples and placed on the surface. This would be the case if a future resident were building a home on the site. We further assume the areal extent is 3000 m^2, the approximate area of SU 9. The NRC model assumes no cover over this contamination. The radioactive contamination is the average of all push probe measurements in SU 9, for the radionuclides Pb-210, Ra-226, Ra-228, Th-230, U-234, U-235 and U-238. Otherwise we take the default assumptions in RESRAD. We assume a person is a resident who has a garden and grows fruits and vegetables. We do not assume the resident is also a farmer, so we ignore the radiation pathways due to milk and meat. We also ignore fish consumption, say from a pond on the property, and radon, the decay product of Ra-226 and Ra-228. In terms of lifestyle, we assume the resident spends half his/her time indoors, 1/4th of the time outdoors on the property and 1/4th the time at work. These are all default assumptions in RESRAD.

The radiation dose calculated by RESRAD is 44.7 mr/y. This is greater than the decommissioning standard of 25 mrem/y, leading us to the conclusion that Fac Pond 8 must be further remediated. The standard set by NY DEC is even more restrictive, 10 mrem/y.

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Ibid, App J for excavation model

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Table 1. Sampling in SU 9 (pCi/g) and Sum of Fractions

	Ra-226	Ra-228	Th-230	Pb-210	U-234	U-235	U-238	Total U	Sum of Fractions		
									5/5/60	RWMA 25 mr/y	RWMA 10 mr/y
Background	0.665		0.636		0.826	0.065	0.819				
SB-01 (11-12)	0.201	**0.553**	-0.129	-0.765	-0.016	-0.02	-0.129	-0.165			
SB01A	1.085	**0.643**	0.585	-0.051	5.247	0.25	4.511	10.008	0.50	0.52	1.30
SB02	10.535	**0.155**	3.348	2.712	3.193	0.285	3.008	6.486	2.88	3.65	9.14
SB03	1.725	**0.323**	-0.043	-0.679	1.975	0.1	1.825	3.9	0.40	0.56	1.40
SB03A	2.595	**0.673**	-0.144	-0.78	3.974	0.107	4.223	8.304	0.63	0.92	2.30
SB03B	2.865	**0.423**	1.51	0.874	3.007	0.058	3.044	6.109	0.98	1.11	2.78
SB04	4.435	**0.138**	2.469	1.833	8.974	0.355	7.966	17.295	1.67	1.68	4.19
SB05	2.695	**0.194**	1.531	0.895	5.621	0.292	5.335	11.248	1.03	1.03	2.57
SB05A	4.685	**0.473**	2.947	2.311	6.834	0.387	6.697	13.918	1.76	1.87	4.68
SB06	2.955	**0.298**	1.297	0.661	5.266	0.476	5.468	11.21	1.04	1.11	2.78
SB07	8.945	**0.148**	42.442	41.806	33.412	1.902	31.728	67.042	11.39	7.41	18.53
SB07A	14.135	**0.523**	6.796	6.16	12.195	0.718	12.355	25.268	4.61	5.30	13.24
SB08	3.195	**0.294**	2.111	1.475	7.073	0.298	7.531	14.902	1.31	1.28	3.20
SB09	3.645	**0.463**	2.47	1.834	6.565	0.331	6.849	13.745	1.45	1.49	3.73
SB10	4.615	**0.112**	2.5	1.864	7.192	0.579	7.244	15.015	1.67	1.73	4.32
SB10A	3.715	**0.443**	1.431	0.795	5.695	0.411	5.639	11.745	1.22	1.40	3.49
SB10B	4.035	**0.336**	2.179	1.543	4.368	0.269	4.674	9.311	1.40	1.54	3.85
SB11	1.055	**0.161**	1.916	1.28	-1.336	-0.089	-2.144	-3.569	0.53	0.49	1.22
SB11A	2.445	**0.197**	1.623	0.987	4.036	0.182	3.207	7.425	0.94	0.94	2.36
Mean	4.187	**0.345**	4.044	3.408	6.488	0.363	6.265	13.116	1.968	1.890	4.726

Table 2. DCGL Values Calculated from RESRAD

Radionuclide	Concentration (pCi/g)	Total	% Contribution	DCGL* (pCi/g)	DCGL** (pCi/g)
Pb-210	1	2.47	11.40%	10.11	4.05
Ra-226	1	7.86	36.22%	3.18	1.27
Ra-228	1	5.72	26.38%	4.37	1.75
Th-228	1	4.97	22.91%	5.03	2.01
Th-230	1	0.05	0.25%	469.92	187.97
U-234	1	0.04	0.17%	664.36	265.75
U-235	1	0.46	2.12%	54.34	21.73
U-238	1	0.12	0.55%	210.44	84.18
		21.69	100.00%		

*Individual TEDE 25 mrem/y

**Individual TEDE 10 mrem/y

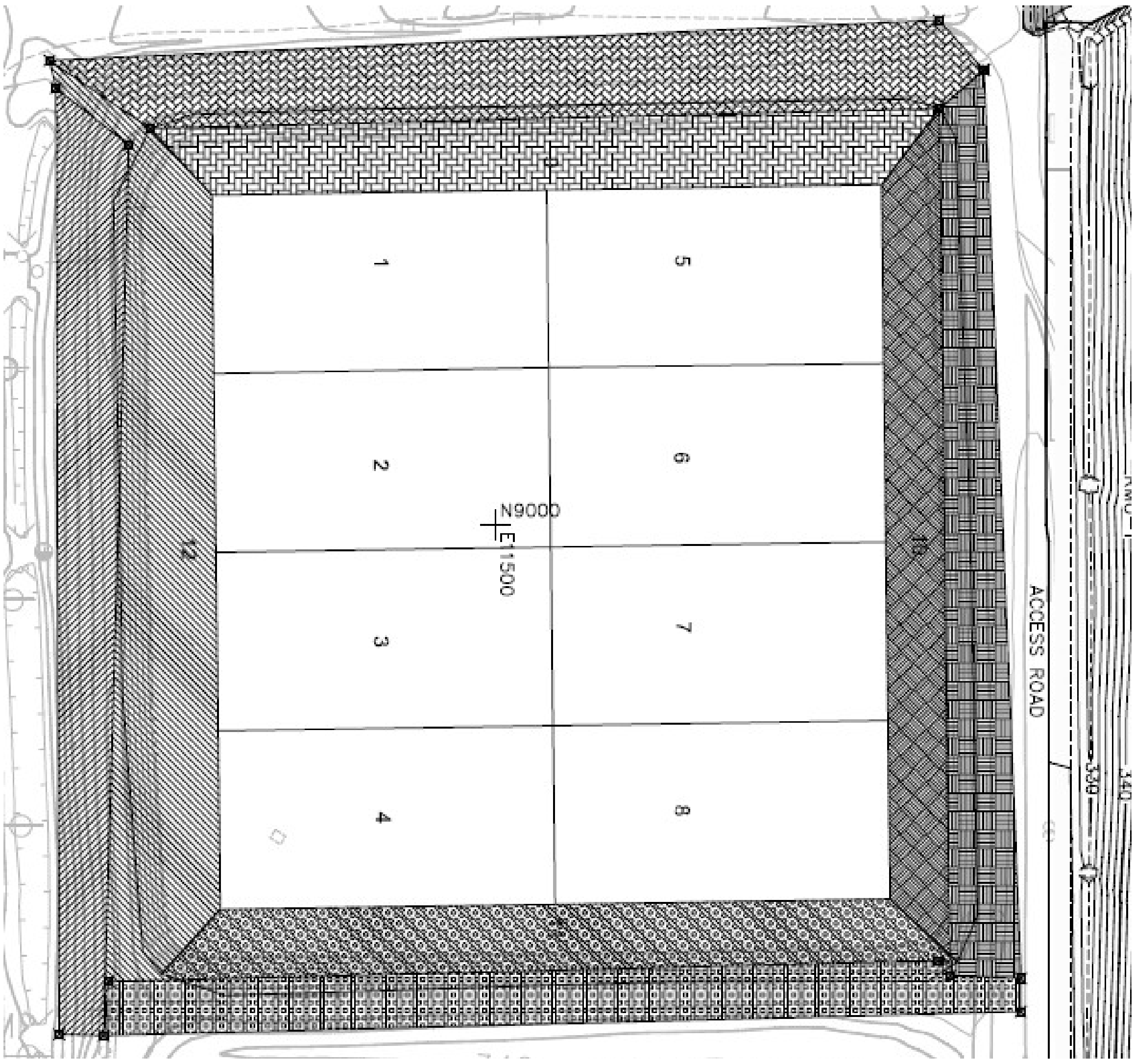


Figure 1. Fac Pond 8, broken into 12 survey units. (LATA, 2012c)

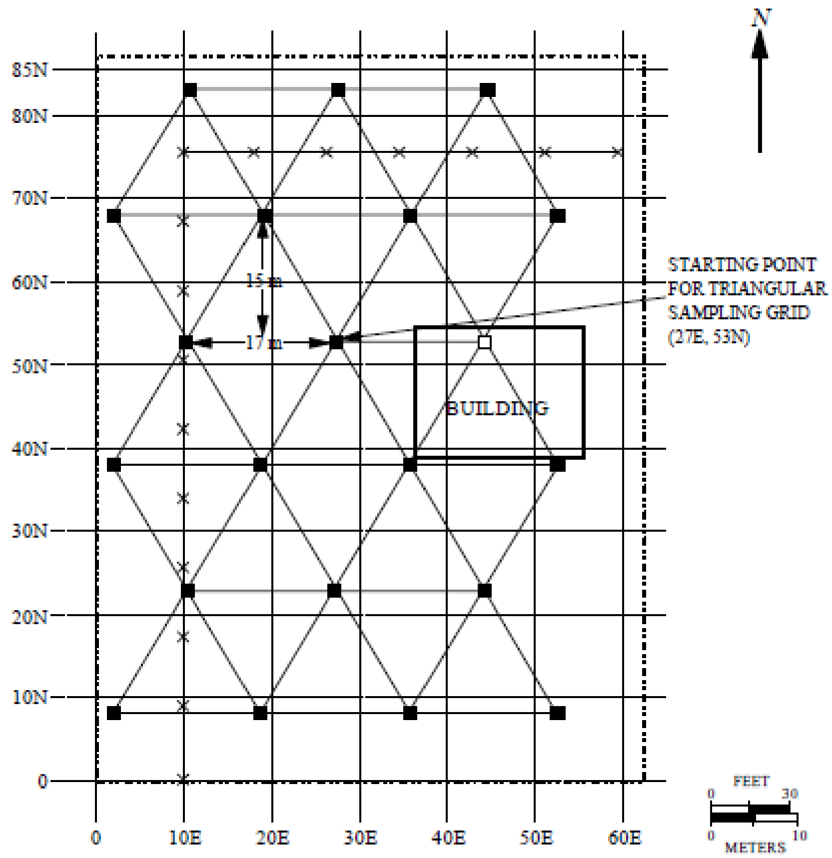
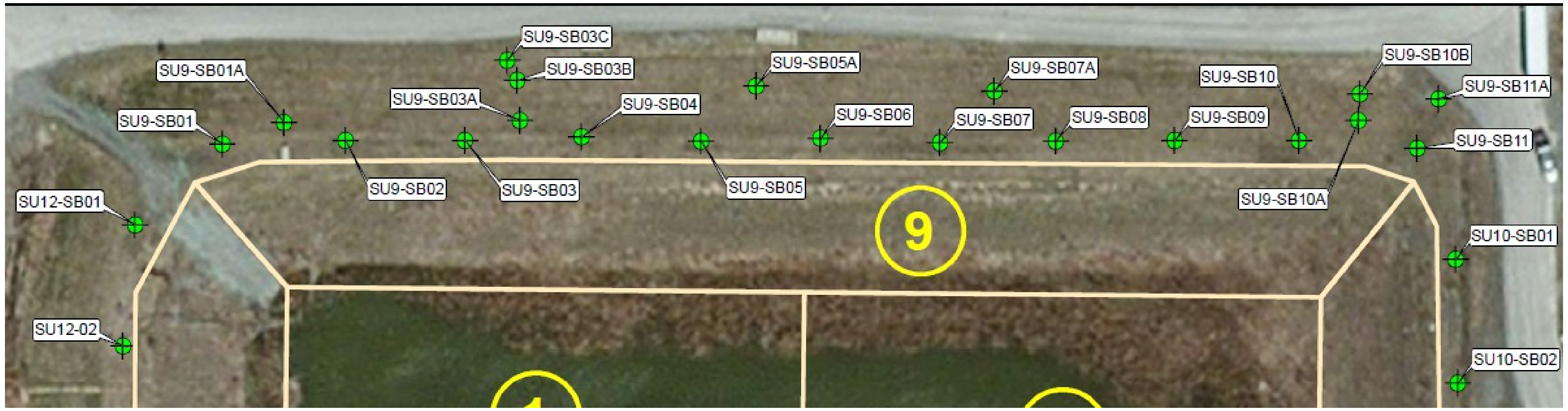


Figure 2a. Sampling Array recommended by MARSSIM (MARSSIM, 2000)

Figure 2b. Deep Probe Samples



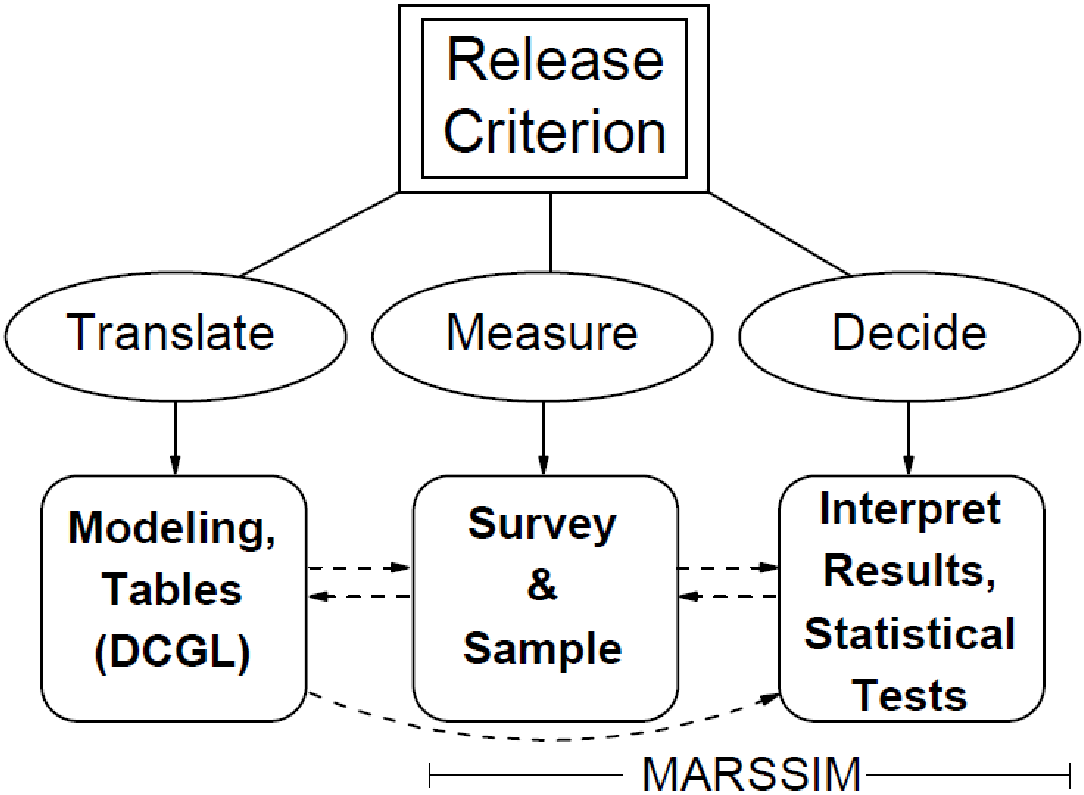


Figure 3. (MARSSIM, 2000), Fig. 1-1.

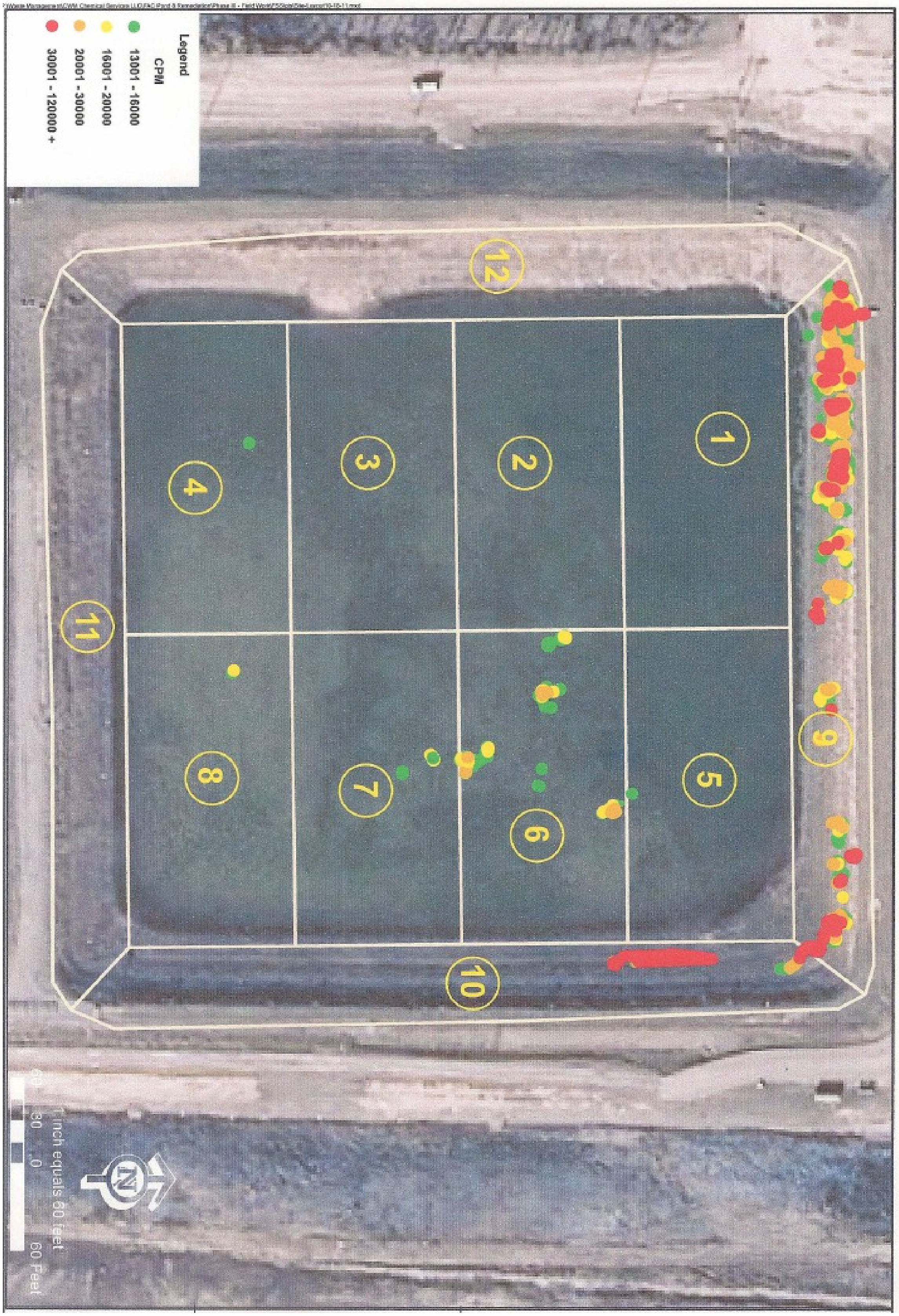


Figure 4. LATA Gamma Surface Sample (LATA, 2012b).

Ra not in Background

	Survey Unit 10	Survey Unit 6	Survey Unit 6+10	Survey Unit 9
alpha =	0.05	0.05	0.05	0.05
Z_a=	1.65	1.65	1.65	1.65
beta =	0.10	0.10	0.10	0.10
Z_b=	1.28	1.28	1.28	1.28
Numerator	8.57	8.57	8.57	8.57
Sign p =	0.58	0.58	0.54	0.86
Denominator	0.03	0.03	0.01	0.53
N=	340.94	340.94	1350.23	16.14

Ra in Background

	Survey Unit 10	Survey Unit 6	Survey Unit 6+10	Survey Unit 9
alpha =	0.05	0.05	0.05	0.05
Z_a=	1.65	1.65	1.65	1.65
beta =	0.10	0.10	0.10	0.10
Z_b=	1.28	1.28	1.28	1.28
Numerator	8.57	8.57	8.57	8.57
Sign p =	0.56	0.56	0.53	0.78
Denominator	0.01	0.01	0.00	0.32
N=	677.58	677.58	2696.76	27.00

$$L = \sqrt{\frac{A}{0.866\ N}}$$ *for a triangular grid*

spacing for triangular grid L = 9.247783 9 meters