YERINGTON MINE SITE FUGITIVE DUST RADIOLOGICAL DOSE ASSESSMENT

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1. SUMMARY

This report conveys the results of a highly conservative radiological dose assessment for exposures to fugitive (windblown) dusts by individuals on- or off-site. The purpose of this study is to determine if individuals in the vicinity of the mine are being exposed to radiation in the form of technologically enhanced naturally occurring radioactive material (TENORM[1]), and what the calculated whole body doses would be. The total effective dose equivalent was determined for several different hypothetical scenarios that are not meant to represent actual people, but that bound what actual exposures might be. This report was prepared with assumptions that are so conservative as to be bounding.

The doses calculated in this report from potential exposure to fugitive dusts from the evaporation ponds and tailings study area are minuscule. The highest annual dose calculated was 0.0015 mrem. The State of Nevada does not regulate Naturally Occurring Radioactive Materials (NORM) or Technologically Enhanced NORM (TENORM) and the material in the tailings area and evaporation ponds are classified as TENORM. Therefore, there are no applicable exposure limits for members of the public. However, the exposure limit for members of the public for materials that are regulated is 100 mrem per year. The doses calculated in this report are more than a factor of 66,000 lower than this limit. As a point of comparison, each person in Nevada will receive up to 300 mrem a year to the whole body (internal and external doses combined) from natural radiation sources. The doses calculated in this report are more than a factor of 200,000 lower than this amount of natural background radiation dose. Finally, it should be noted that, in the context of these bounding dose estimates, the actual doses to a real person would be much lower; additional data and effort would be required to estimate actual doses, but such effort is unwarranted, given the small bounding doses estimated in this study.

2. INTRODUCTION

The Nevada Department of Environmental Protection (NDEP) requested that SRK Consulting prepare a work plan to characterize selected tailings areas and evaporation ponds at the Yerington mine site in Nevada. The work plan was designed to provide data required to determine the metal content and radiological characteristics of the surface materials in selected areas that could generate dust. This information was then used to determine radiation doses and metal exposures, which is the subject of this report. The results of this investigation are presented in Appendix A

The areas of concern, shown on Figure 1, are the Finger evaporation ponds, evaporation ponds, and portions of mill tailings. The Finger and evaporation ponds were used to evaporate various process water streams during mine operation. These ponds accumulated various mineral salts on the surface from the evaporation process. Likewise, the tailings pond accumulated surface salts from the evaporation of the liquid component of the tailings. These evaporative salts potentially contain Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM). The NDEP is concerned that these materials, when dry, could be wind borne and migrate off-site.

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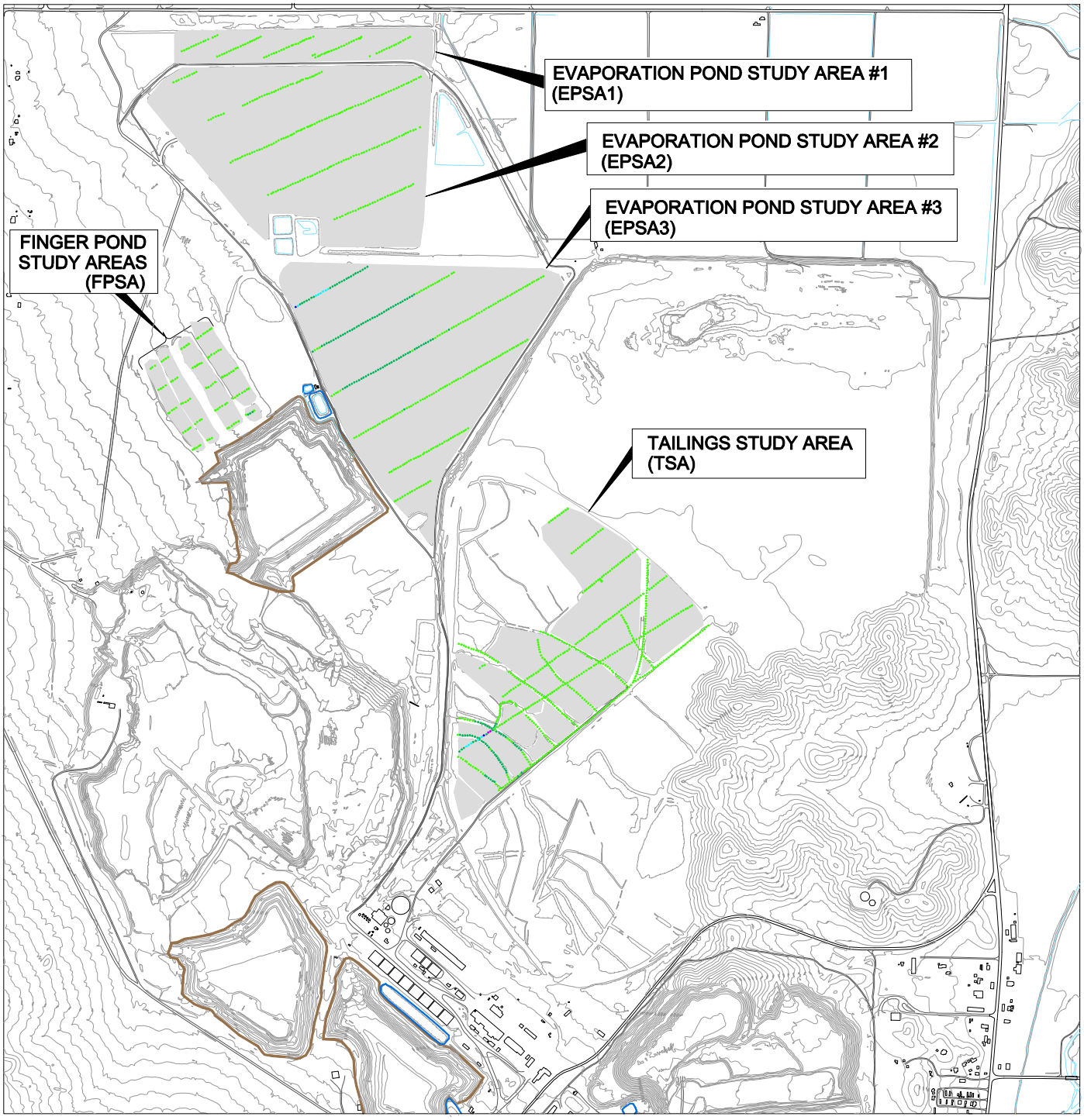
[1] TENORM is the term used to describe naturally occurring radioactive material that has been altered in concentration and/or location.



EXPLANATION

STUDY AREA

GAMMA SURVEY POINT

- 0-30 µR/hr
- 31-60 µR/hr
- 61-90 µR/hr
- 91-120 µR/hr
- >120 µR/hr

0 250 500
FEET

REFERENCE			
DESIGNED	RG	7/04
DRAWN	draft	7/04
CHECKED	JS	7/04
APPROVED		

REVISIONS No.	DESCRIPTION	DATE

FIGURE 1

YERINGTON EMAR
STUDY AREA LOCATIONS

PREPARED BY: SRK Consulting Engineers and Scientists

SCALE: 1"= 500'
REVISION A

JOB NO. 113922
DWG NAME 113922-SA

The surficial materials in the study areas are generally characterized as follows:

1. The Finger ponds have evaporative salts from mine dewatering that are covered with local alluvial material to mitigate dust generation.
2. The salts on the evaporation ponds came from mine dewater fluids that were flooded over the surface of mill tailings.
3. The salts on the tailings area accumulated from the evaporation of tailings fluids. The tailings area also contains berms made of coarse oxide vat leached minus 3/8 inch tailings. The NDEP is proposing to spread these coarse berm materials over the majority portion of tailings study area to mitigate dust generation. Five samples of the berm materials will be collected separately from the surficial samples for characterization.

Surface samples were collected along five transect lines within each study area, except for the largest evaporation pond, which had six transects. The transects are generally aligned with the direction of the prevailing winds in the area, from the southwest to the northeast. Prior to the collection of the surface material samples, a walking radiation survey was conducted along the transect lines. Gamma measurements were made from one meter above the surface along the transect line. The operator monitored the gamma activity and noted the readings approximately every thirty feet. The endpoints of each line were located with a handheld GPS instrument. The operator also recorded the location of any anomalous (high) readings relative to surrounding measurements between intervals. The interval was then resumed from the noted location along the transect. After the survey was completed, the location of the seven highest readings along each transect were determined. Surface material samples were collected at these locations. If more than seven locations had similar gamma activity, the seven locations that best represented the transect line were selected. The berm samples were collected within the Tailings Study Area.

Once the sample locations along the transect were determined as described above, a surface sample was collected at each location. Surface materials were collected at each location to a depth of approximately two inches below the surface. The transects were labeled A through E from north to south in each study area. The sample locations from each transect were labeled from one to seven with the location the highest gamma reading being number one. The study areas were abbreviated as follows:

1. Finger Pond Study Area – FPS
2. Evaporation Pond Study Area 1 – EVP1
3. Evaporation Pond Study Area 2 – EVP2
4. Tailings Study Area – TSA

As an example of the alphanumeric designations used, the resulting sample identification for the northern most transect in the Evaporation Pond Study area for the third highest gamma reading is EPS-A-3. (SRK 2004)

3. BACKGROUND

3.1. Yerington Mine site

The Yerington Mine is located at Weed Heights, in Lyon County, Nevada, approximately 80 miles south-southeast of Reno. Activities that have taken place over the life of this site include exploration, development, and open pit mining of a large, oxidized-copper ore deposit. From 1952 to 1978 mined copper oxide ore was leached with a sulfuric acid solution and the copper was recovered as cement copper. This cement copper was then shipped off to a smelting facility and then to another facility for further refinement.

The industrial facility at the Yerington Mine site consisted of a variety of units. A large open pit mine was the source of the basic ore, which was blasted from its surroundings following removal of overburden. Historically, ore material was then divided into three categories and piled separately: the material containing less than 0.2-percent copper was classified as waste and piled furthest from the plant (to the north of the pit). The rock containing 0.2- to 0.4-percent copper was piled separately, nearer the plant, and the material containing 0.4-0.6-percent copper was stockpiled nearest the plant.

At the plant the ore was milled, starting with the primary crushing machine. Once the initial crushing was completed, the ore was stored in a pile where it was subsequently blended with other grades or ore from other parts of the pit. Ore drawn off this coarse ore-storage pile was delivered to the secondary crushing unit, where it was run over a series of eight screens and then delivered to the leaching vats by a series of three conveyors. Prior to leaching, the ore in each vat underwent agglomeration and bedding to ensure no segregation or channeling of solution or blockage of the circulation of the leaching solution. The process of bedding, leaching, draining the ore, followed by excavation of the residue, was an eight day process and took place in eight 12,000 ton concrete tanks.

The pregnant-copper solution was stored in two 286,000 gallon tanks, and then pretreated and sent to the cementation part of the plant where it was precipitated. The cemented copper was then cleaned and rinsed in several processes and heated to lower the moisture content. Once dry, the cement copper was loaded from a drying hearth into specially designed trucks and hauled off to the smelter.

From 1989 to 1999 copper oxide ores were mined from low grade stock piles, vat leach tailings and the Macarthur pit. The mined copper ores were stacked in heaps on a total of five lined heap leach pads. Copper was extracted from the leach pad heaps with a dilute 1% sulfuric acid solution. The resulting pregnant leach solution (PLS) was collected in catchment ponds at each of the individual heaps. The copper bearing PLS solution was then pumped to a solvent extraction and electrowinning plant (SXEW). Using an organic reagent and kerosene the copper was extracted from the PLS. The copper was then stripped from the organic reagent with a strong sulfuric acid solution, which produced a copper-bearing electrolyte. The copper was then electrowon from the solution and 99.99 fine copper sheets were produced as a final product. After the copper was extracted from the PLS it was circulated back to the heaps for reuse. This was a zero discharge process.

The copper heap leach and SXEW operation ceased copper production in 1999 and was put on a care and maintenance status. SRK Consulting was contracted by the Nevada Division of Environmental Protection to manage the leach pad drain down fluids at the site. As a part of the fluid management system in 2000, five electric powered evaporators were installed at one of the heap leach pads to enhance fluid evaporation. SRK Consulting has managed the heap leach fluids since January 2000 on a continual basis. It is anticipated that the site will require some level of fluid management over the next several years.

3.2. Natural Radiation Background

Radiation exposure to all members of the general public occurs continually. People are exposed to three broad categories of radioactive sources: natural radiation, technologically enhanced natural radiation, and anthropogenic (man-made) sources. Natural radiation can be further subdivided into terrestrial, cosmic, and cosmogenic sources. Terrestrial radionuclides include the uranium-, thorium-, neptunium- and actinium-series, as well as a few non-series isotopes, e.g., K-40 and Rb-87, which occur in the air, soil and water throughout the entirety of the earth. Cosmic radiation includes those particles and rays, which originate in the solar system and beyond, that reach the earth. Cosmogenic radionuclides are those formed as a result of cosmic radiation interactions in the atmosphere, like H-3, C-14 and Na-22. Finally, TENORM refers to terrestrial NORM that has been concentrated and/or exposed to the accessible environment through human activities. Annual dose equivalents due to these natural background sources vary from around 300 mrem in the United States (Table 1) to as high as approximately 2,700 mrem in Kerala, India (NCRP 1987).

Table 1. Effective dose equivalents, H_E, from exposure to natural sources, as averaged over the United States population, per annum.

Source:	H_E, mrem y^{-1}:
Terrestrial	28
Cosmic	27
Cosmogenic	1
Inhalation	200
Internal	39
Total:	~300

As can be seen in Table 1, external doses primarily result from exposure to gamma rays of cosmic and terrestrial origin. Internal doses are completely dominated by inhalation of the short-lived progeny of Rn-222 ("inhalation" in the table above). Further internal exposure occurs when the body irradiates itself from materials incorporated into a person's tissues ("internal" in the table above). This is understandable when we consider nuclides such as the H-3 and C-14 (above) are incorporated into the human bodies as a normal part of the metabolism – C-12 and C-14 look like carbon to the body because the human body does not distinguish between nuclei, only atoms.

Site historical documents indicate that uranium salts accumulated in the evaporation ponds and that uranium is present in the groundwater at the Yerington Mine site at background levels (SRK 2003). The tailings study area has also been identified as an area containing TENORM.

3.3. Radiological Assessment

A radiological dose, *D*, may be determined by actually measuring and/or assessing the following:

$$STU=D \tag{1}$$

In this expression, *S* stands for the source term, *T* the transport factor used to characterize movement of the radioactive source material to the point of interest, and *U* the usage factor, which describes the accumulation of a nuclide in a medium to which the person in question has been exposed.

Everything on the left side of the equation expressed above, which is generally described as a dose pathway, requires either measurement or assumption of the values that go into the calculation (NAS NRC 1995). Qualified measurement data should always be used in place of assumptions where those data are available. Thus, inhalation, ingestion and external exposure dose assessments were derived from applicable measurement data, where available. Such data would represent the "S," "T," and even possibly the "U" factors in Equation 1 above, depending on the nature of the measurement.

As indicated above, a radiological dose assessment begins with a determination of the source term. The source term encompasses both the identity and the radioactivity of any radioactive nuclides present at the point of emission. Radioactivity is a term we use to describe an amount of radioactive material. Each different kind of radioactive atom has its own unique rate of decay; thus, the need for determining the identity of any radioactive elements present at the source. This decay rate is used with knowledge (or an assumption) as to the number of radioactive atoms present, to calculate the radioactivity of a source.

Radioactivity is a very important quantity in dose assessment. How much something might be expected to decay is also a description of how much energy is introduced into the dose pathway, this energy being in the form of radiation as previously discussed. Since a radiological absorbed dose is defined as energy deposited per unit mass it stands to reason that low radioactivity makes for a low energy-introduction rate, which will result in a low-dose-rate.

It should be noted that higher activity does not automatically result in the potential for elevated dose either. For example, Rn-222 (a gas) has such a short half-life, 3.8-days, that it may decay into Po-218 (a solid), prior to diffusing out of a formation, thus rendering the nuclide and any other progeny relatively immobile. This is to say that a radon atom may decay so rapidly as to have effectively removed itself and any further progeny from producing an environmental exposure to humans.

One must also know the identity of any radionuclides posed in an exposure scenario because, as with the aforementioned decay rate, each radioactive nuclide emits a unique combination of

particles and energy (radiation). If the emitted radiation poses an insignificant threat to people at the end of the dose pathway, because of low yield, slow decay rate, low particle energy, improper chemical form etc., then it should be excluded from further consideration. Such professional judgment on the part of the radiological dose assessor speaks to the importance of making the correct assumptions when determining which possible dose pathways should be investigated.

Once we know the identity and amount of radioactive material present we must start to determine how much of that material and/or its emitted radiations make it to the point of interest. The distance between the source of radiation and the person in question is a necessary first-step in determining the transport and fate of a nuclide for a given dose pathway.

The distance between a source of radiation and some point beyond the source is important in two ways. First, if the dose is the result of an external irradiation, particles emitted by the radioactive substance (alphas, betas, gammas etc.) must get from point "a" to point "b" in the dose pathway. The number of particles reaching from the source to the receptor falls off very rapidly with distance under most circumstances (Shapiro 1990). Since these particles carry the energy that would become the dose, the dose rate falls off rapidly with distance, as well. This reduction simply happens because the particles are more spread out as one gets further away from the radiation source. Simply geometry illustrates this as shown in Figure 2.

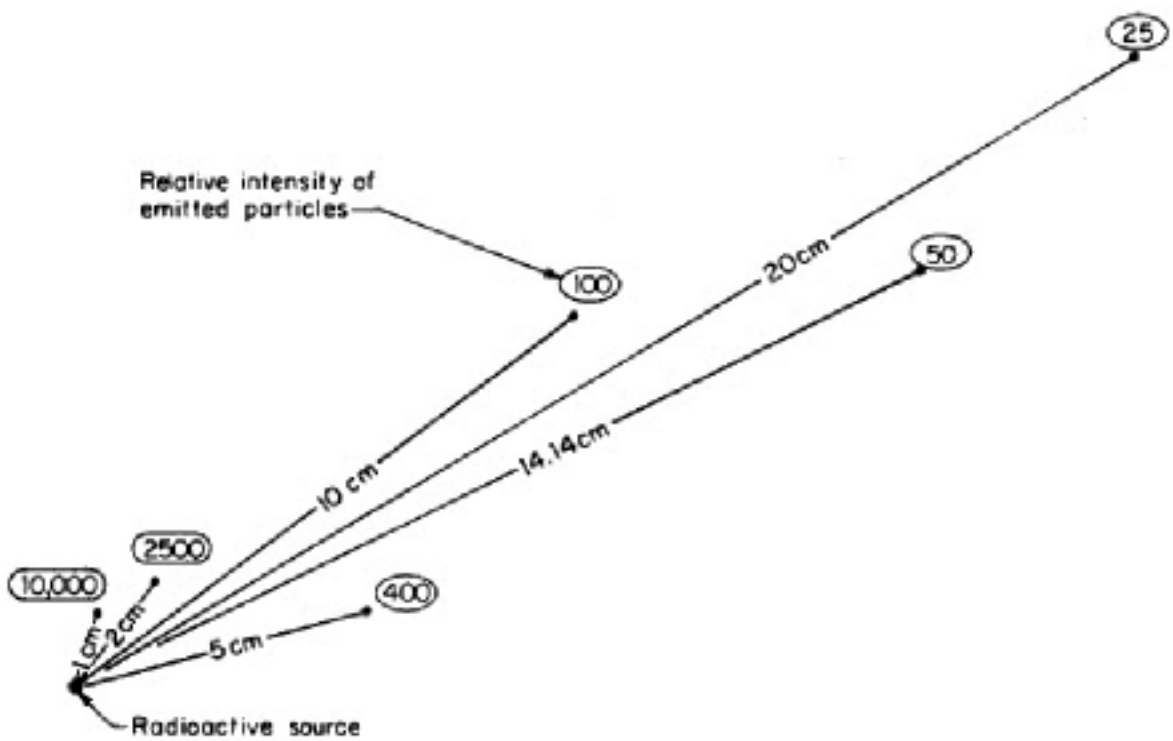


Figure 2. Examples of a decrease in dose with increasing distance, i.e., geometric attenuation (after Shapiro 1990).

Some radionuclides pose a potential internal hazard rather than an external irradiation hazard; this is the second instance in which distance may factor into a dose assessment. In this case the

radioactive atoms, rather than the radiation emitted, must reach the person in question. Distance is once again a critical determinant in the dose pathway because gases and particles must first reach the person at the end of said pathway before they may be of any potential harm. Gases and particles will diffuse and mix convectively into the atmosphere from their point of origin, and will quickly begin to settle out, analogous to the "spreading out" described above for radiation. The distance it takes for a given concentration of radionuclide to settle out will be dominated by meteorological and geological conditions (wind speed, atmospheric stability, thermal gradients, surface roughness, vegetation, rainfall, etc.) and physical properties of the particles such as size, density, shape and charge.

Physical properties of the radioactive atoms under study also determine whether or not the airborne substance poses any internal hazard. For inhalation doses, even when a particle reaches a person it must be of respirable dimension – some particle sizes are more optimal than others for penetrating the human respiratory tract. Put another way, many of the particles a person might be exposed to are too large to be respirable (a term that indicates penetration to the deep lung); some are even too large to be inhaled (a term that indicates passage through the mouth or nose). Beyond this, properties such as chemical form and half-life again become important. That is, even if a particle reaches the body, and it is of the right size and form to be distributed within the body, it must decay for there to even be a potential for harm. The mere presence of a radioactive atom in the body does not imply that harm has or will be done to that body. Soluble radioactive chemicals, which are those most likely to enter circulation in the body, are also among those most likely to be eliminated from the body. If a radioactive atom passes from the body before it decays then there has been no dose deposited, even though the atom was in the body at some point. Oftentimes, uranium is highly soluble in the body and typically passes through the body quickly, with little absorption (NRC 1986).

In addition to the distance between source and person, the physical nature of emitted radiation will also determine its penetrating ability. As has been stated previously, particles will spread out as they transit away from the source and only some fraction of these radiations will actually be headed in the direction of the receptor. Even though these particles are headed in the "right" direction some will not make it because they will have transferred all the kinetic energy to surrounding materials such as the air, clothing etc. and if no energy is deposited then there can be no radiation absorbed dose.

3.4 Performance of Bounding Assessments

A complete radiological dose assessment involves several steps (See Section 3.3, Radiological Assessment). The most important step is to assess the dose to an individual from all sources of exposure if it is suspected that radiation well in excess of background levels is present. Dose is the index by which the probable risk of all present or future health effects may be postulated. In the health physics profession, an absorbed "dose" is a quantity of energy absorbed by some portion of an organ or tissue of the person in question (Cember 1996, Turner 1995). The *rad* is the traditional unit for quantification of radiation absorbed dose. In the context of ionizing radiation, absorbed dose (usually just referred to as dose) is adjusted for the quality of the

radiation, i.e., multiplication by a quality factor[2], and this dose equivalent (traditional unit – *rem*) is used by qualified persons to make a judgment about the potential someone exposed to a particular kind of radiation has for suffering short-term or long-term health effects. If an individual does not receive a dose well in excess of the natural radiation background, then no risk of health effects may be assigned[3].

One standard practice during a radiological dose assessment is to calculate the "bounding" set of doses for a potentially exposed population. A bounding dose estimate is determined in such a highly conservative fashion that a potentially exposed individual could never actually incur such a dose. Bounding dose estimates are usually determined at the outset of a study as an aid in judging whether a more detailed assessment effort is even warranted. If the bounding doses are so low as to be considered negligible from a radiation health standpoint, then the study usually goes no further.

We calculated a set of bounding dose estimates for each of a set of potentially exposed individuals (hypothetical workers and members of the public) at the Yerington Mine site based on the information reviewed, as discussed above. The bounding conditions are discussed in detail in Section 4. An additional benefit of bounding calculations is that, as the name implies, bounding calculations "bound" any potential uncertainties associated with more detailed calculations that may be performed. Bounding calculations should not be confused with conservative or "worst case" dose estimates. That is, conservatism in dose estimation is achieved by calculating the highest possible dose that may be achieved using approved methodology and sound professional judgment. In addition to being a responsible health physics practice, this is a directive of several agencies (NRC 1992). Bounding estimates differ from worst-case estimates because it is understood that the bounding dose could never occur. Worst-case scenarios, while highly conservative, do contain some possibility, although highly remote, of occurrence. Worst-case dose estimation is useful for planning purposes, for *a priori* estimation, or dose projection for some process in the future. Such a system of estimation should not be used for *a posteriori* dose assessments, or dose reconstruction after the fact, because actual data exists concerning what, where, how, and when the people in question may have been exposed.

4. METHODOLOGY

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[2] Quality factor is a method used in radiation protection to convert absorbed dose quantities to dose equivalent quantities. Quality factors make all radiations equivalent (thus the term dose equivalent) with respect to the expected amount of biological change afforded by a dose.

[3] It is a commonly held misconception that "there is radiation, therefore there is harm." In actuality, the passage of radiation through living material will produce chemical changes, the majority of which are harmless to the individual as a whole. The International Commission on Radiological Protection (ICRP) distinguished between four terms in an attempt to achieve some clarity on this subject: change, damage, harm and detriment. Changes, which occur naturally thousands of times an hour in the human body, may or not be harmful. Damage represents some degree of deleterious change; however, the damage may be deleterious to the effected region, e.g., a cell, while being completely inconsequential to the organism as a whole (the person with the cell). Harm is used to describe those deleterious changes (damage) that will affect the whole organism or its offspring. Finally, detriment combines probability, severity, and time of expression of harmful effects. It is this final term that receives the most attention in a retrospective radiological dose or risk assessment (ICRP 1990).

To calculate an individual's radiation dose, one has to consider pathways that might release particulate or gaseous radioisotopes to the environment, which may be subsequently inhaled or ingested, as well as direct exposure to gamma and some beta ray-emitting materials. For this study, the external irradiation and ingestion pathways do not have the potential to contribute any meaningful dose. Dust concentrations on the ground off-site of the Yerington mine are not known to be significant contaminated with dusts from the mine. Even on the mine site, only specific areas have radionuclide concentrations above what one would consider as background levels. Therefore, the remainder of this report focuses on doses from inhalation of airborne dusts.

4.1 Characterization of Dust Sources

There are five different sources of dust: three evaporation ponds, the finger ponds (as one entity), and the tailings storage area. Because of the proximity of these sources to each other, they are being considered collectively as one dust source. In order to consider them collectively, an average, or representative, concentration of all of the contaminants in the material must be determined.

Within each dust source, or feature, there are five (or six for EVPSA-3) transect spaced approximately equally apart, but of varying lengths. The fraction of the total surface area of each feature represented by a given transect is roughly proportional to the ratio of the given transect to the total length of the five (or six) transects for that feature. The contaminant composition for each transect, and thus for that fraction of the total surface area, is obtained by averaging the results for the seven samples taken from the points of the highest gamma exposure rate. By taking the samples at the locations of the highest gamma exposure rates, the results thus obtained should be biased high, resulting in a bounding dose assessment as discussed in Section 3.4. The contaminant composition for each feature is determined by the area-weight average of the composition for each transect. Similarly, the representative concentration for all five features is determined by an area-weighted average of the composition for each individual feature. The results of this weighted averaging are given in Table 2.

The total surface area of the dust sources at the mine is 1265.4 acres, or 5.12 km^2, which can be visualized as a square 2.26 m on a side. In actuality, the dust sources are more rectangular with the long side perpendicular to the prevailing wind direction from the SW. Using a square source in the modeling results in a conservative result since there is more linear distance in the direction of the wind from which material can be suspended.

4.2 Atmospheric Transport

The analysis of the atmospheric transport of fugitive dusts can be divided into discrete steps. The first is the determine the source term. How much material is being lifted into the air? Next, the site-specific meteorology can be analyzed in conjunction with atmospheric dispersion models to determine where the dust goes and what the dust concentration is. This dust concentration is then used to calculate the amount of material actually inhaled and the resulting dose.

Table 2. Representative soil constituent concentrations.

Analyte	Value	Units	Analyte	Value	Units
Clay	15.27	%	Aluminum	5888.13	mg/kg-dry
Moisture	17.86	%	Antimony	0.10	mg/kg-dry
Sand	11.28	%	Arsenic	11.15	mg/kg-dry
Silt	73.45	%	Barium	32.26	mg/kg-dry
Density	2.24	g/cc	Beryllium	0.00	mg/kg-dry
Actinium 228	6.30	pCi/g	Boron	224.90	mg/kg-dry
Bismuth 214	1.10	pCi/g	Cadmium	0.06	mg/kg-dry
Gross Gamma	30.55	pCi/g	Calcium	49410.03	mg/kg-dry
Lead 212	8.80	pCi/g	Chromium	10.30	mg/kg-dry
Lead 214	1.49	pCi/g	Cobalt	24.95	mg/kg-dry
Potassium 40	6.46	pCi/g	Copper	517.65	mg/kg-dry
Radium 224	29.05	pCi/g	Iron	142542.84	mg/kg-dry
Radium 226	1.11	pCi/g	Lead	7.86	mg/kg-dry
Radium 228	6.24	pCi/g	Magnesium	4523.90	mg/kg-dry
Thorium 228	5.04	pCi/g	Manganese	267.52	mg/kg-dry
Thorium 230	24.63	pCi/g	Mercury	0.12	mg/kg-dry
Thorium 232	4.44	pCi/g	Molybdenum	9.40	mg/kg-dry
Thorium 234	1.05	pCi/g	Nickel	10.14	mg/kg-dry
Uranium 234	7.83	pCi/g	Potassium	3911.17	mg/kg-dry
Uranium 235	0.23	pCi/g	Selenium	0.74	mg/kg-dry
Uranium 238	6.09	pCi/g	Silver	0.00	mg/kg-dry
			Sodium	14530.13	mg/kg-dry
			Thallium	3.37	mg/kg-dry
			Vanadium	18.32	mg/kg-dry
			Zinc	26.23	mg/kg-dry

4.2.1 Fugitive Dust Emissions

The suspension factor, or source term, is perhaps the most crucial and most difficult parameter to determine for suspension of particulates. This factor describes the amount of dispersible material that actually goes airborne. Consideration must first be given to the wind speed over area of interest, in this case the evaporation ponds and tailings study area, and then to the size distribution of the particles that comprise the material. The methodology from NUREG-0706, "Final Generic Environmental Impact Statement on uranium milling," for calculating fugitive dust emissions from uranium mill tailings was used to calculate the fugitive dust emissions from

the tailings study area and the evaporation ponds. The characteristics of the materials present in the Yerington mine tailings and evaporation ponds are quite similar to the materials which make up uranium mine tailings since the processes which generate these materials and the resultant particle sizes are also similar (NRC 1980).

Particle size distribution data for the dust particles from the laboratory analysis, and depicted in Fig. 3, was used to determine the average particle size of material in transport. The average size of dust grains is approximately 540 µm (µm is a way of denoting "micron," a measurement of length equal to one-millionth of a meter[4]).

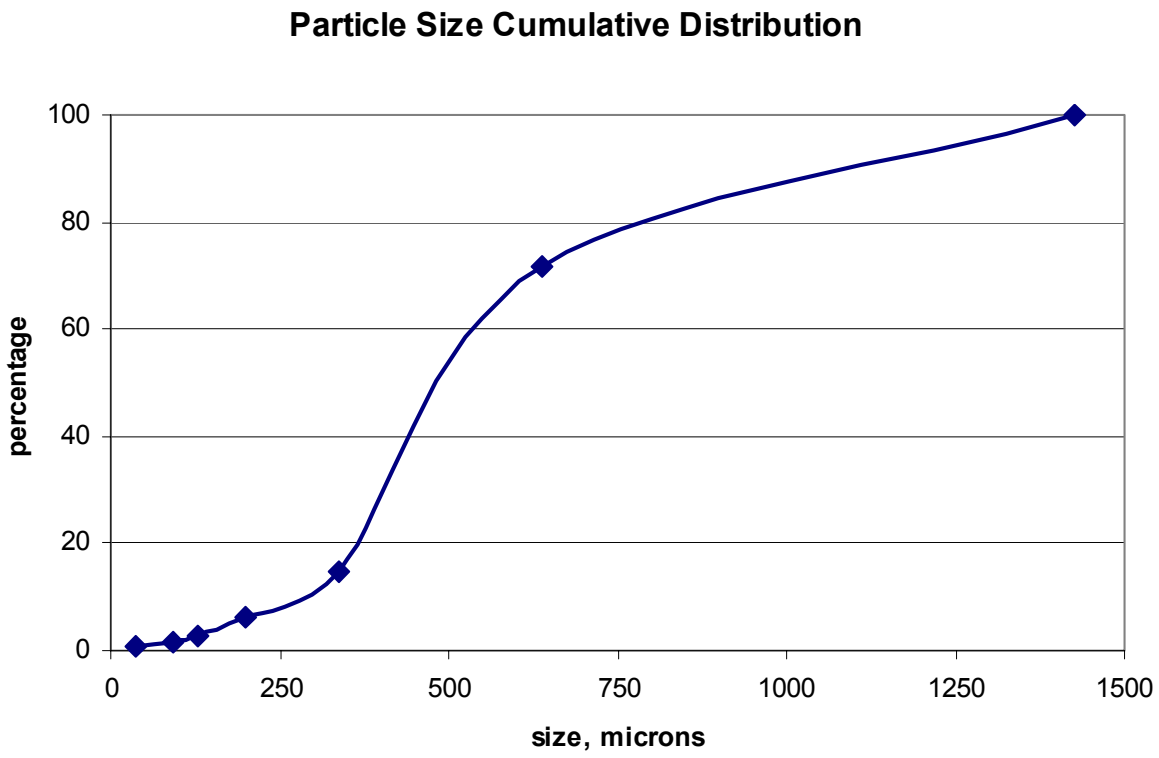

Figure 3. Dust Particle Size Distribution

Given the above particle size distribution, one must examine the various processes that describe the movement of soils and sands by wind: surface creep, saltation, and suspension (DOE 1994; Fig. 4). Surface creep is a process that affects particles in the particle size range of 500 – 1000 micron. Surface creep describes the sliding and rolling of these larger particles, which are too massive to become airborne. Saltation describes the motion of particles in the size range of about 100 to 500 micron, wherein smaller particles are launched into the air (suspended) when these intermediate-sized particles land. Saltation is a skipping or jumping motion and the particles that are acted upon transfer momentum[5] to smaller particles as they land. Finally,

[4] As a point of reference, a human hair is about ninety- to one hundred-microns in diameter.

[5] Think of momentum transfer in the context of two billiard balls, one regular-sized and one smaller, perhaps the size of a golf ball. When the larger ball strikes the smaller ball the smaller one will absorb energy from the larger, and this transfer will have a more pronounced affect because the second ball has less

suspension describes the motion of particles smaller than approximately 100 micron, a motion wherein particles are lifted off the surface by a wind-induced shear stress. All of these particle sizes ranges are approximate; there will be some overlap of these processes.

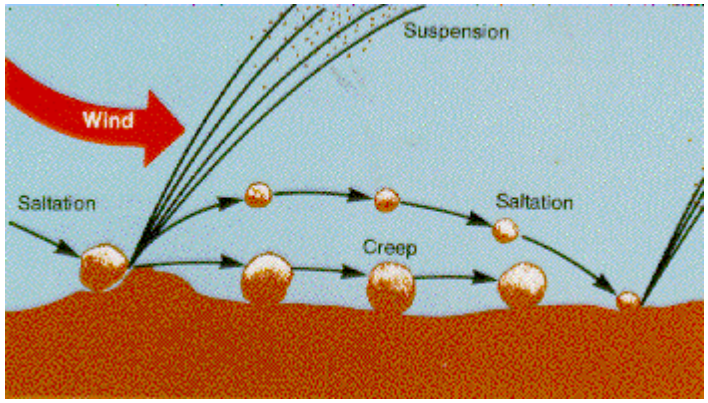

Figure 4. Depiction of wind erosion processes involved in ore suspension.

Saltation moves the greatest amount of material. Surface creep will not appreciably lift particles off of the surface of the ground. In addition, experimental evidence shows that particles small enough to undergo suspension do not readily suspend due to wind forces acting directly upon them. Rather, it is by the momentum transfer of larger, saltating particles landing on these smaller particles that actually sends them airborne. Dust particles less than 50 micron, and especially less than 10 micron (respirable particles – the ones that could go on to be inhaled and lead to a dose) are extremely resistant to wind erosion (Sehmel 1980, Chepin 1943, Bagnold 1941). Respirable particles do not tend to go airborne via wind-induced stresses because of a number of factors, not the least of which is their small size – the threshold wind speed required to suspend particles increases as the particle size decreases, the ability of smaller particles to agglomerate, or stick to other particles, increases as size decreases, and the suspension-arresting effect of capillary action due to moisture increases as size decreases. Suspension (respirable) particles would not be eroded readily were it not for saltation (Sehmel, 1980).

To determine the amount of dust that is lofted by the wind, one must begin by determining the saltation rate of dust particles. We begin with the aforementioned size distribution and each mean wind speed. First, the surface sheer velocity, or friction velocity for a given wind speed is determined. This is a complicated way of saying that we determine the maximum lifting force that could "push" a grain of ore because of the maximum wind speed (assumed by solving the following wind velocity profile formula for sheer velocity, U^* (NRC 1988):

$$U_z = U^* \left[2.5 \ln(z/z_0) \right], cm/s \qquad (2)$$

where

U_z is wind velocity, 40 mph in this case,

mass.

U^* is the sheer velocity afforded by the assumed wind velocity, and

The term in brackets describes the wind profile between a height, z, and the ground, as described by a surface roughness term, z_o.

The height, z, is the height at which the wind speed is measured, which was conservatively assumed to be 1 meter, even though the height at which the wind speed was measured was higher. This will maximize the saltation rate and thus the vertical particle flux since a lower height will increase the calculated wind speed at ground level.

The surface roughness factor, z_o, is usually taken as one-tenth of the longest dimension of the average size of material under consideration. Surface roughness is important because it indicates that those particles resting on top of surface ridges, or bumps, dunes etc. are more easily lofted, while those lying between such ridges are less easily lofted. We assumed a very conservative surface roughness of 1 cm.

The threshold wind velocity, U_t^* must next be calculated. This factor describes the minimum shear velocity required for saltation to begin in a given bed of particles, i.e., the evaporation salts in the ponds. If the shear velocity afforded by the mean wind speed, U^*, exceeds this threshold velocity, then saltation will occur and the aforementioned momentum transfer process will carry aloft suspension particles ($U^* > U_t^*$ for saltation to occur). If the calculated shear velocity does not exceed the threshold velocity, then saltation does not occur and no particles will become airborne. The threshold velocity may be calculated by:

$$U_t^* = A\sqrt{\frac{\sigma-\rho}{\rho}\cdot gd}\cdot(1.8+0.6\cdot\log_{10}W),\ cm/s \tag{3}$$

where

A is a dimensionless coefficient, evaluated as approximately 0.1 for particles >100 micron diameter in air,

σ is the density of the dust from Table X , 2.2 g/cm^3,

ρ is the density of air, 1.293x10^{-3} g/cm^3,

g is the gravitational constant for planet earth, 980 cm/s^2,

d is the average diameter of the dust grains, or 540 microns, and

W is the soil moisture content, 17.9% as given in Table 2, which along with the rest of the term in brackets, accounts for the increase in threshold velocity observed as moisture content increases.

Our calculation of the threshold velocity yielded:

$$U_T^* = 0.1\sqrt{\frac{2.24-0.0012}{0.0012}\cdot 980\cdot 0.054}(1.8+0.6\log_{10}17.9) = 80.2,\ {}^{cm}\!/_{s} \tag{4}$$

The horizontal particle flux rate, q, describes the movement of particles along the material on the ground (Fig. 6). Again, this formula indicates that particles will only move if the afforded shear velocity exceeds the threshold shear velocity:

$$q = CU^{*2}(U^* - U_T^*),\ and\ q = 0\ for\ U^* < U_T^*,\ {}^{g}\!/_{cm \cdot s} \tag{5}$$

where C is a constant of proportionality, given as 10^{-6} g s^2/cm^4

Finally, the vertical flux, V, that is always associated with a horizontal particle flux, which is indicative of the suspension factor, is given by the following (for 20 micron particles or smaller, as presented):

$$V_{20} = q\left[\frac{C_V}{U_T^{*3} \cdot C_h}\right] \cdot \left[\left(\frac{U^*}{U_T^*}\right)^{p/3} - 1\right],\ {}^{g}\!/_{cm^2 \cdot s} \tag{6}$$

where

C_V and C_h are empirically derived constants for particles below 20 micron (the respirable particles that we are ultimately interested in for our dose assessment), given as $2x10^{-10}$ and 10^{-6}, respectively (Gillette 1973), and

p is the fraction of suspended particulates less than 20 micron in diameter, , which is taken as 0.615% from Fig. 2 for particles smaller than 75 microns.

Our calculation for the vertical flux, which is the amount of material less than or equal to twenty micron that goes airborne as a function of bed area and time, with a 25 mph wind yielded:

$$V_{20} = (0.16) \cdot \left(\frac{2x10^{-10}}{80.2^3 \cdot 10^{-6}}\right) \cdot \left[\left(\frac{97.1}{80.2}\right)^{0.2625/3} - 1\right] = 2.44x10^{-12}\ {}^{g}\!/_{cm^2 \cdot s} \tag{7}$$

The foregoing methodology was used to calculate the amount of dust that becomes airborne per unit area. The results of this analysis indicate that only winds above 20 mph will result in respirable particles becoming airborne. A 25 mph wind will result in a suspension rate of $2.44x10^{-8}$ g/m^2-s, which is the value used for the remainder of the analysis.

4.2.2. Meteorological Profile of Yerington Mine

Meteorological data was available from an on-site weather station for calendar year 2003. The station recorded the wind direction and speed at 10 minute intervals except for 180 missing readings (30 hours) on December 8, 9, and 12. From this data, a joint frequency distribution was calculated as a function of wind speed and direction for 8 wind directions and 6 wind speed ranges. Figure 5 displays the results. The weather station at the mine does not provide any information usable for determining the stability class, which is an important factor in determining the dispersion and transport of dusts downwind. Data from which the stability class could be derived was obtained from National Weather Service records for Reno, NV, the closest location

for which data was available. Due to terrain differences and the resulting differences in prevailing wind directions, the data was used to generate stability class distributions as a function of wind speed range. Figure 6 displays the results. No attempt has been made to account for the effect of rain, either in suppressing atmospheric transport or in increasing the moisture content of the soil.

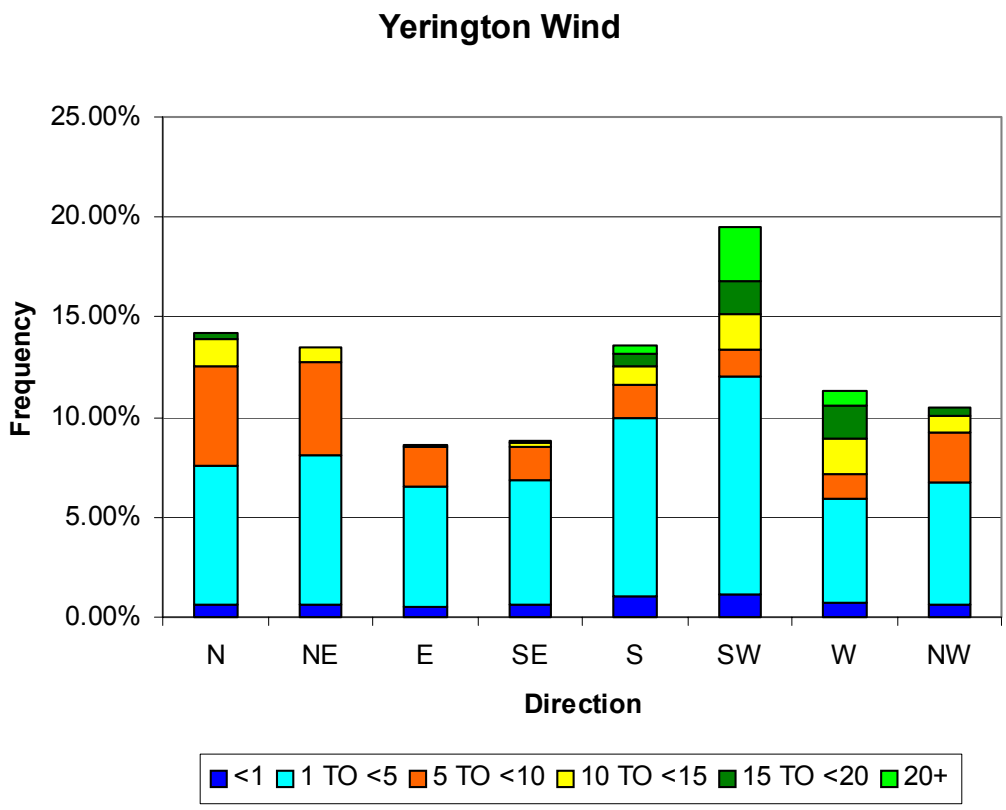

Figure 5. Yerington Wind Conditions.

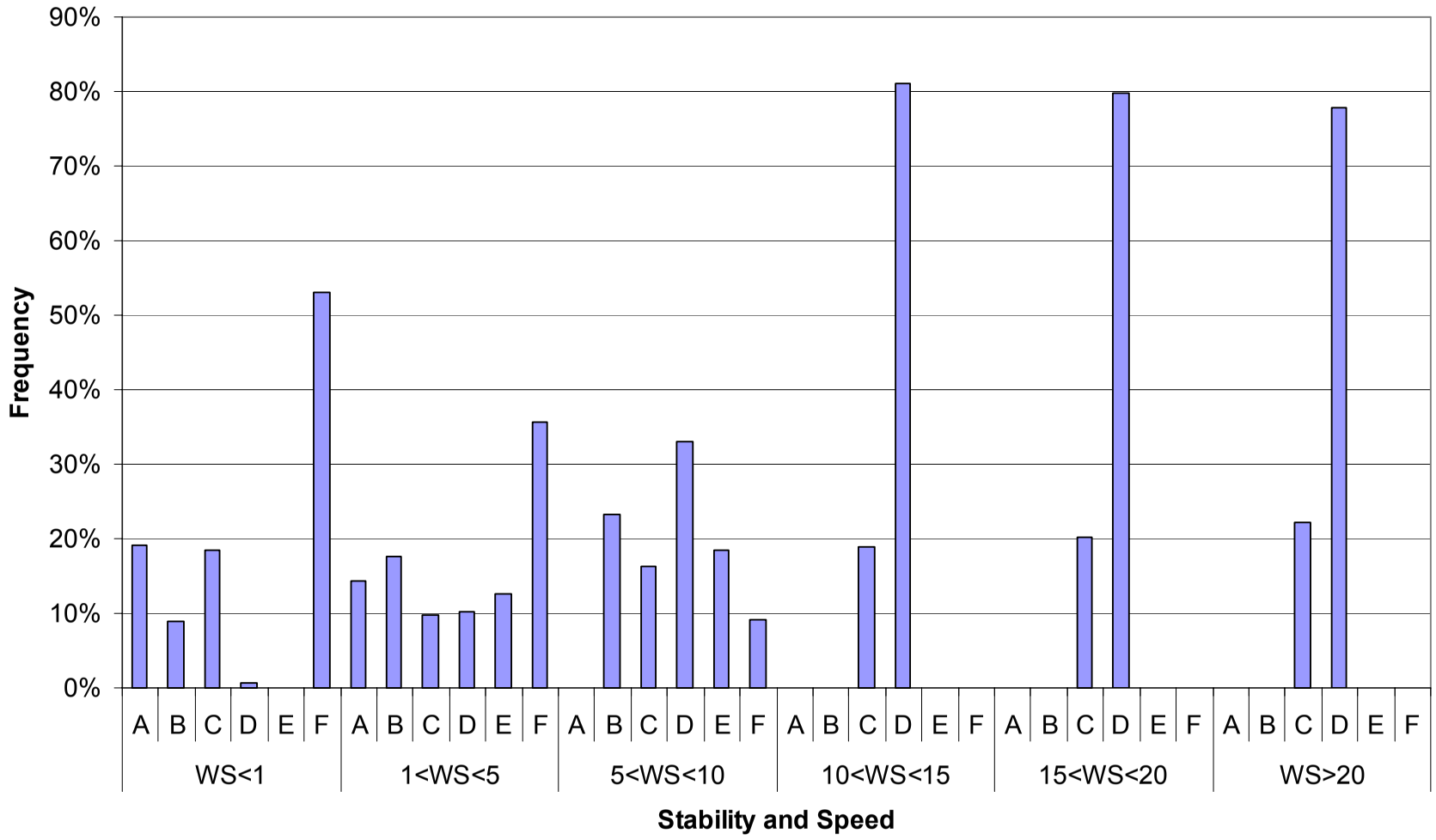

Figure 6. Stability Class for each Wind Speed Range.

4.2.3 Dispersion Calculations

The dispersion analysis was performed with the SCREEN3 code. This code, although over 10 years old, was preferable over newer codes. More recent codes, such as ISC3 and CALPUFF, are more powerful codes which consider site topography and meteorology, but they do not allow for the use of source terms that vary as a function of wind speed. SCREEN3 can be operated in a mode which permits the input of different source terms for each wind speed and stability desired.

Although dispersion analyses were made for the whole spectrum of wind speeds and stability classes, only the highest wind speed bin, 20+ mph, is relevant since only these winds suspend respirable particulates. At this wind speed, only stability classes C and D exist. Table 7 below gives the annual average dust concentration in the air for fugitive dust from the evaporation ponds as a function of wind direction and distance downwind in meters. Note that the table gives wind direction, so a person South of the mine would use the North wind column.

Table 3. Annual average dust concentrations downwind for each wind direction.

Distance (m)	N	NE	E	SE	S	SW	W	NW
0	5.33E-11	8.89E-12	1.78E-11	3.11E-11	9.07E-10	6.32E-09	1.67E-09	8.00E-11
500	2.50E-11	4.17E-12	8.34E-12	1.46E-11	4.25E-10	2.97E-09	7.84E-10	3.75E-11
1000	1.92E-11	3.21E-12	6.41E-12	1.12E-11	3.27E-10	2.28E-09	6.03E-10	2.89E-11
1500	1.63E-11	2.71E-12	5.43E-12	9.50E-12	2.77E-10	1.93E-09	5.10E-10	2.44E-11
1900	1.47E-11	2.44E-12	4.89E-12	8.55E-12	2.49E-10	1.74E-09	4.59E-10	2.20E-11
2900	1.20E-11	2.00E-12	4.00E-12	7.01E-12	2.04E-10	1.42E-09	3.76E-10	1.80E-11
3900	1.04E-11	1.73E-12	3.46E-12	6.05E-12	1.76E-10	1.23E-09	3.25E-10	1.56E-11
4900	9.19E-12	1.53E-12	3.06E-12	5.36E-12	1.56E-10	1.09E-09	2.88E-10	1.38E-11
5900	8.28E-12	1.38E-12	2.76E-12	4.83E-12	1.41E-10	9.82E-10	2.60E-10	1.24E-11
6900	7.54E-12	1.26E-12	2.51E-12	4.40E-12	1.28E-10	8.94E-10	2.36E-10	1.13E-11
7900	6.91E-12	1.15E-12	2.30E-12	4.03E-12	1.17E-10	8.19E-10	2.16E-10	1.04E-11
8900	6.36E-12	1.06E-12	2.12E-12	3.71E-12	1.08E-10	7.53E-10	1.99E-10	9.54E-12

4.3 Dose Calculations

From the airborne dust concentrations calculated by the dispersion analysis, the amount of material inhaled can be calculated and this can then be used to calculate a person's dose. The dose has been calculated for three age groups, 1 year olds, 10 year olds, and adults. This is done in two steps: 1) calculation of the mass of material inhaled or ingested, and 2) calculation of the dose from this amount of material.

The amount of material inhaled is calculated by multiplying together the air concentration, the amount of time that concentration is present, and the breathing rate for each age group. This inhaled mass is multiplied by an age-dependent dose conversion factor to yield the dose from the inhaled material. Table 7 gives the average annual concentration, i.e., the concentration averaged

over the full 8760 hours per year. For adults, the breathing rate for light activity from ICRP 66 (ICRP 1990) of 1.5 m^3/hr was used to be conservative. In actuality, a person off-site would spend a large portion of their time asleep or awake and sedentary, and thus breathing at a much lower rate. For 1 year olds and 10 year olds, light activity breathing rates of 0.35 and 1.35 m^3/hr respectively were used similar to that used for adults.

The ICRPDOSE2 program was used to obtain Total Effective Dose Equivalent (TEDE) dose conversion factors (DCFs) that can be used to calculate a person's dose from the amount of material inhaled. ICRPDOSE2 uses DCFs from ICRP 72 and 68. For all the radionuclides present, the slowest lung clearance class was used as a conservatism and a particle size of 5 microns was used since this is the default value recommended by the ICRP and is also conservative for this case since the average particle size will be much larger given that the assumption that all the mass less than 75 microns in size is respirable has already been made. Table 4 lists the dose conversion factors used. For the U-238 decay chain and for U-235, the results of the laboratory analysis for each isotope or the closest parent isotope were used for the concentrations. For the Th-232 chain, the average value of all the isotopes in the decay chain was used.

Table 4. Dose Conversion Factors.

Nuclide	Conc.	Adult	10 year old	1 year old
	pCi/g	mrem/g	mrem/g	mrem/g
U-238	6.09	1.47E-01	1.76E-01	3.38E-01
Th-234	1.05	2.52E-05	3.53E-05	1.05E-04
U-234	1.05	3.03E-02	3.57E-02	6.60E-02
Th-230	24.63	1.09E+01	1.18E+01	1.82E+01
Ra-226	1.11	3.23E-02	3.81E-02	7.37E-02
Pb-214	1.49	1.11E-04	1.38E-04	2.87E-04
Bi-214	1.10	9.39E-05	1.27E-04	3.14E-04
Pb-210	1.10	1.96E-02	2.33E-02	4.49E-02
Bi-210	1.10	2.90E-04	3.31E-04	6.53E-04
Po-210	1.10	1.31E-02	1.51E-02	3.02E-02
Th-232	9.98	4.80E+00	5.54E+00	8.49E+00
Ra-228	9.98	4.80E-01	5.54E-01	1.03E+00
Ac-228	9.98	1.14E-03	2.44E-03	5.91E-03
Th-228	9.98	1.33E+00	2.18E+00	5.54E+00
Ra-224	9.98	1.07E-01	1.18E-01	1.70E-01
Pb-212	9.98	6.64E-03	8.86E-03	1.55E-02
Bi-212	9.98	1.59E-03	1.99E-03	4.43E-03
U-235	0.23	6.08E-03	7.21E-03	1.39E-02
SUM		**1.79E+01**	**2.05E+01**	**3.41E+01**

5. DOSE ESTIMATES

Calculating the dose for a representative person consists of multiplying the average air concentration at their location from Table 3, by 8760 hours a year (or some smaller number if they are not there 100% of the year), by their breathing rate (1.5 m^3/hr for adults from Section 4.3), and by the appropriate DCF (17.9 mrem/g for adults from Table 4).

For an adult standing on the northeast edge of the study areas, the resulting annual dose from remaining at that location for an entire year is 0.0015 mrem. For an adult 1 km downwind, or approximately at the site boundary, this drops to 0.0007 mrem. The doses for a 10 year old at the same locations are the same. The increase in the DCF is offset by the reduction in the breathing rate. For a 1 year old, the doses are 0.0006 mrem and 0.0003 mrem respectively. Other directions and distances will be even less due to the lower frequency of high winds and/or longer distance.

6. CONCLUSIONS

The doses calculated in this report from potential exposure to fugitive dusts from the evaporation ponds and tailings study area are minuscule. The State of Nevada does not regulate NORM or TENORM and the material in the tailings area and evaporation ponds are classified as TENORM. Therefore, there are no applicable exposure limits for members of the public. However, the exposure limit for members of the public for materials that are regulated is 100 mrem per year. The doses calculated in this report are more than a factor of 66,000 lower than this limit and more than a factor of 200,000 lower than the amount of natural background radiation dose a person living in Nevada receives.

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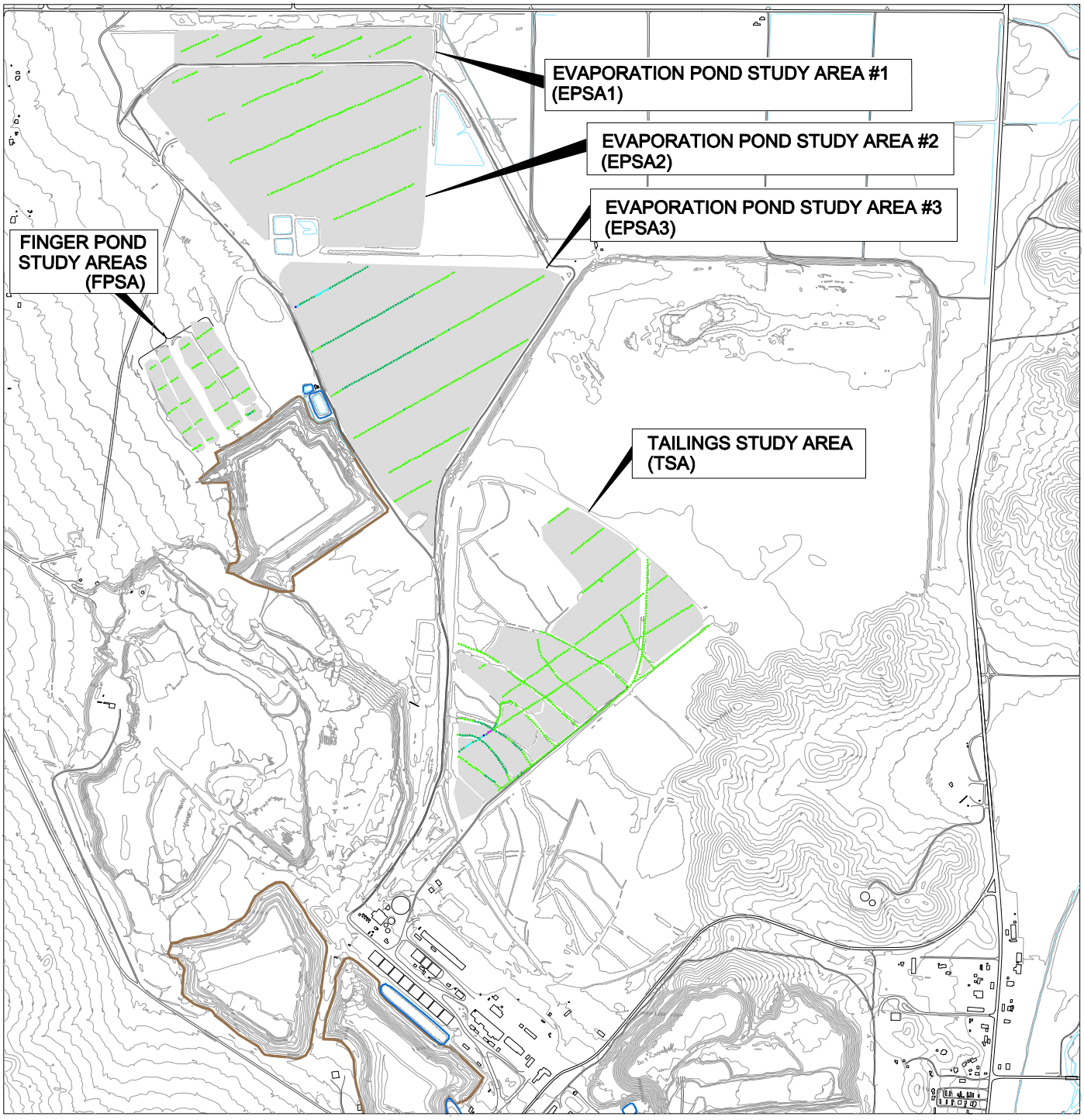
APPENDIX A
Survey and Lab Analysis Results



EXPLANATION

STUDY AREA

GAMMA SURVEY POINT

- 0-30 µR/hr
- 31-60 µR/hr
- 61-90 µR/hr
- 91-120 µR/hr
- >120 µR/hr

0 250 500
FEET

REFERENCE			
DESIGNED	RG	7/04
DRAWN	draft	7/04
CHECKED	JS	7/04
APPROVED		

REVISIONS No.	DESCRIPTION	DATE

FIGURE 1

YERINGTON EMAR
STUDY AREA LOCATIONS

PREPARED BY: SRK Consulting Engineers and Scientists

SCALE: 1"= 500'
REVISION A

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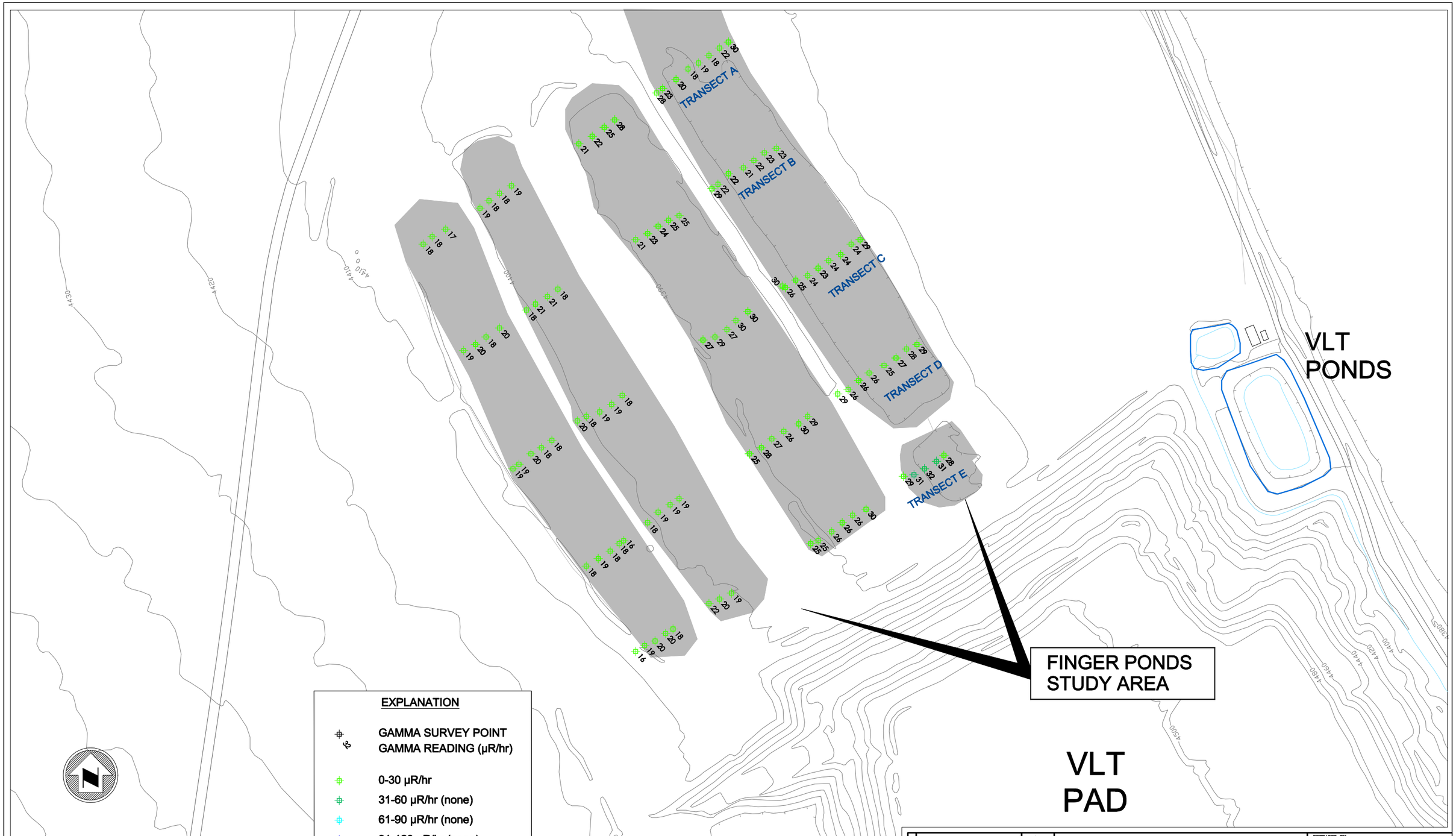

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APPROVED			

REVISIONS No.	DESCRIPTION	DATE

FIGURE 2

YERINGTON EMAR

GAMMA SURVEY
FINGER PONDS STUDY AREA

PREPARED BY: SRK Consulting Engineers and Scientists

SCALE: 1"= 200'

REVISION A

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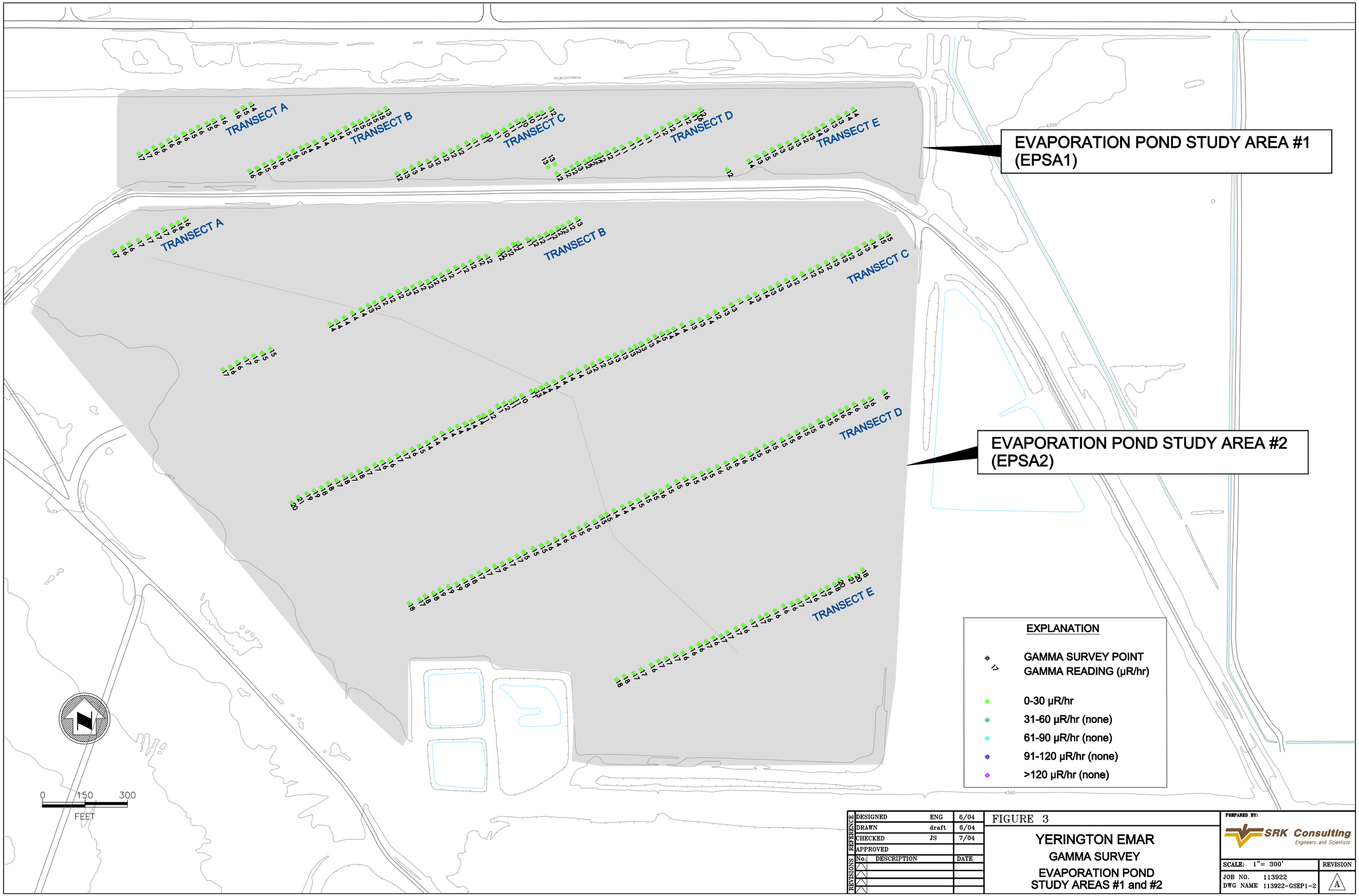

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APPROVED		

REVISIONS No.	DESCRIPTION	DATE

FIGURE 3

YERINGTON EMAR
GAMMA SURVEY
EVAPORATION POND
STUDY AREAS #1 and #2

PREPARED BY:
SRK Consulting
Engineers and Scientists

SCALE: 1"= 300'

REVISION A

JOB NO. 113922
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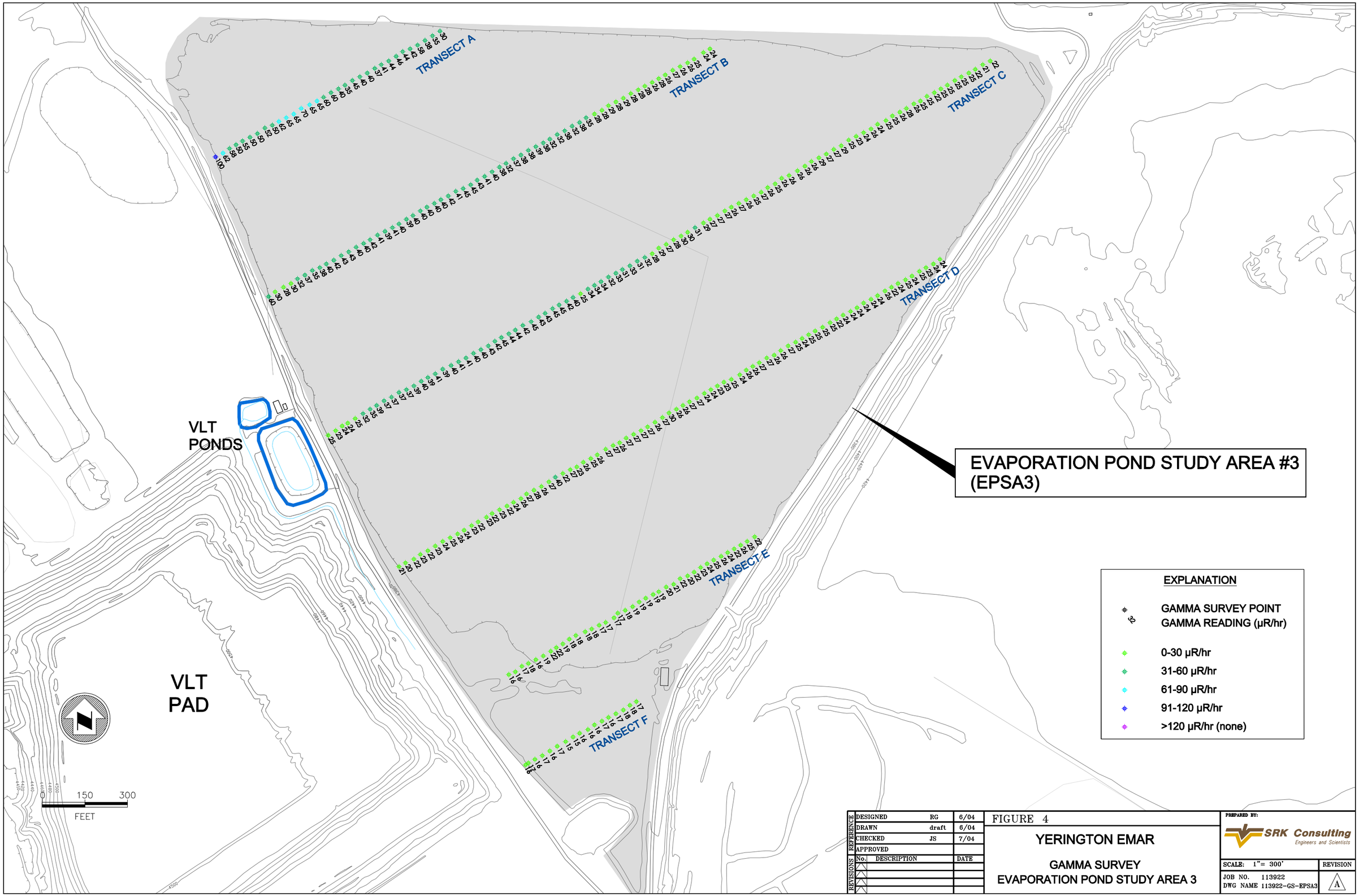

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CHECKED	JS	7/04
APPROVED		

REVISIONS No.	DESCRIPTION	DATE

FIGURE 4

YERINGTON EMAR

GAMMA SURVEY
EVAPORATION POND STUDY AREA 3

PREPARED BY: SRK Consulting Engineers and Scientists

SCALE: 1"= 300'

REVISION A

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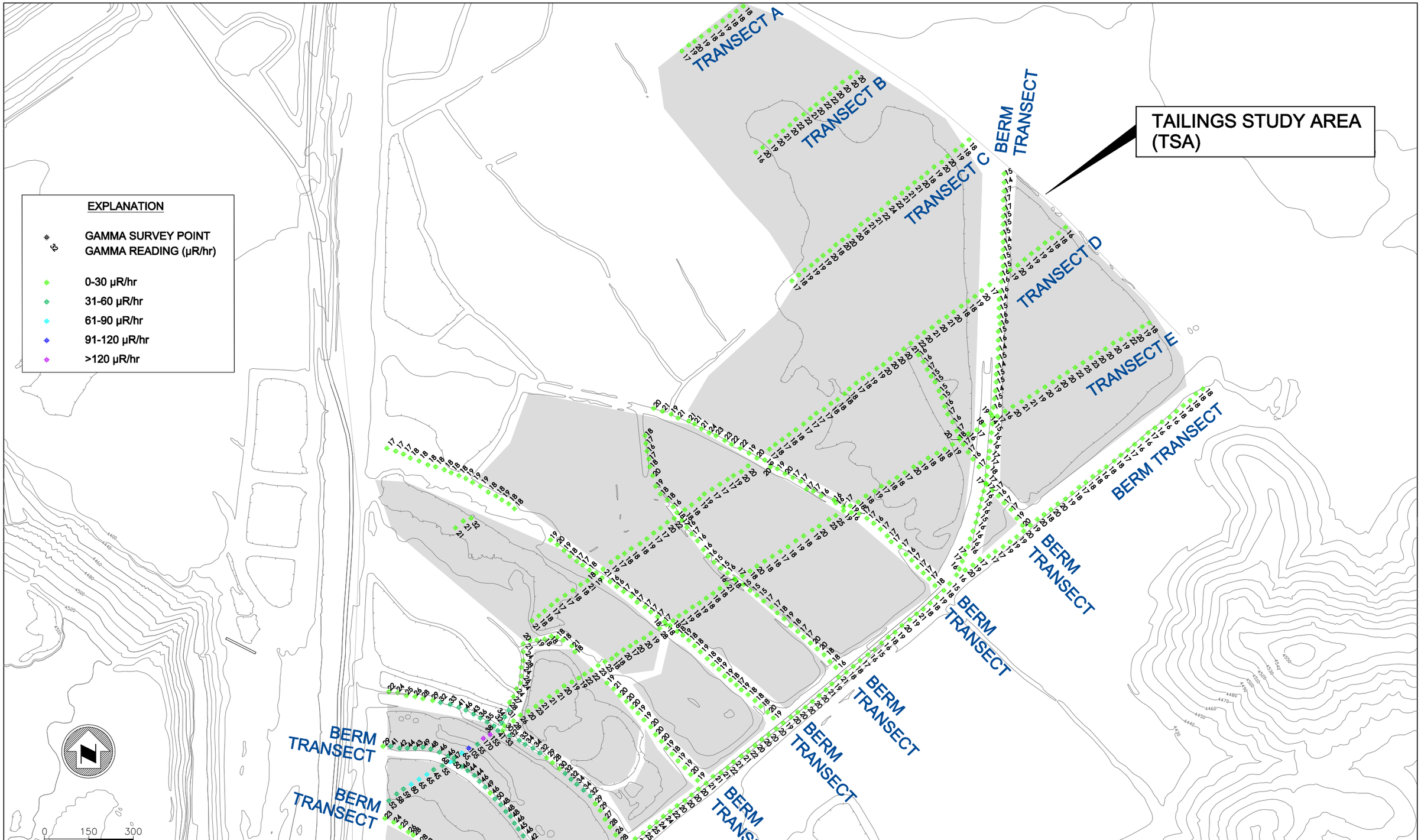

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	CHECKED	JS	7/04
	APPROVED		
REVISIONS	No.	DESCRIPTION	DATE

FIGURE 5

YERINGTON EMAR

GAMMA SURVEY
TAILINGS STUDY AREA

PREPARED BY:
SRK Consulting
Engineers and Scientists

SCALE: 1"= 300'

REVISION A

JOB NO. 113922
DWG NAME 113922-GS-TSA