Vista Technologies Inc.
Radiation Safety Program

PROCEDURE - 5

RADIATION HAZARDS

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Note: For the purposes of this document, Ionizing Radiation includes certain types of Non-Ionizing Radiation.

ABBREVIATIONS AND ACRONYMS

α	-	Alpha
ß	-	Beta
γ	-	Gamma
μ	-	Micro
^{241}Am	-	Americium-241
^{137}Ce	-	Cesium-137
^{234}Pa	-	Protactinium-234
^{210}Pb	-	Lead-210
^{210}Po	-	Polonium-210
^{214}Po	-	Polonium-214
^{218}Po	-	Polonium-218
^{232}Pu	-	Plutonium-232
^{226}Ra	-	Radium-226
^{228}Ra	-	Radium-228
^{219}Rn	-	Radon-219 (Actinium Series)
^{220}Rn	-	Radon-220 (Thorium Series)
^{222}Rn	-	Radon-222 (Uranium Series)
^{89}Sr	-	Strontium-89
^{90}Sr	-	Strontium-90
^{230}Th	-	Thorium-230
^{232}Th	-	Natural Thorium
^{238}U	-	Uranium-238
µCi	-	MicroCurie
µCi/hr	-	MicroCuries per hour
µCi/ml	-	MicroCuries per milliliter
µM	-	Micrometer
µR/hr	-	MicroRoentgen per hour
µg/mg	-	Microgram per milligram
ALARA	-	As low as reasonably achievable
ALI	-	Annual limit on intake
ANSI	-	American National Standards Institute
APR	-	Air-purifying respirator
Bq	-	Becquerel
Bq/m^3	-	Becquerels per cubic meter of air
BZ	-	Breathing Zone
C	-	Coulomb
C/kg	-	Coulombs per kilogram
CDE	-	Committed Dose Equivalent
CEDE	-	Committed Effective Dose Equivalent

CFR	-	Code of Federal Regulations
Ci	-	Curie
CIH	-	Certified Industrial Hygienist
CFM	-	Cubic feet per minute
CLIA	-	Clinical Laboratories Improvement Act
CLP	-	Contract Laboratory Program
cm	-	Centimeter
cm/sec	-	Centimeters per second
cpm	-	Counts per minute
CPR	-	Cardiopulmonary resuscitation
CSE	-	Certified Safety Executive
(D)	-	Duplicate count
DAC	-	Derived air concentration
DAC-h	-	DAC hours
DCA	-	Double Contingency Analysis
DDE	-	Deep Dose Equivalent
DI	-	De-ionized water
DOT	-	U.S. Department of Transportation
dm^2	-	Square Decimeter; one square decimeter equals 100 square centimeters
dpm	-	Disintegrations per minute
dpm/cm^2	-	Disintegrations per minute per square centimeter
dpm/dm^2	-	Disintegrations per minute per square decimeter
dps	-	Disintegrations per second
DRD	-	Direct reading dosimeter
DU	-	Depleted uranium
EPA	-	U.S. Environmental Protection Agency
eV	-	Electronvolt
FE	-	Feces sample
FIDLER	-	Field instrument for detection of low energy radiation
FR	-	Filter ratio
FSP	-	Field Sampling Plan
ft^2	-	Square foot
γ	-	Gamma ray
GA	-	General area
GeLi	-	Germanium - Lithium
G-M	-	Geiger-Mueller
GMC-H	-	Mine Safety Appliances Company, full-facepiece, dual ..combination filter cartridges for an APR
GPD	-	Gaseous Diffusion Plang
h	-	hours
He-3	-	Helium Three (3)

HEPA	-	High efficiency particulate air
HNO_3	-	Nitric acid
HP	-	Health Physics
hr	-	Hour
HS	-	Hot spot (radiation)
HSP	-	Site-specific Health and Safety Plan
HWP	-	Hazardous Work Permit
ICRP	-	International Commission on Radiological Protection
ID	-	Identification
IDLH	-	Immediately dangerous to life or health
IDW	-	Investigation derived waste
IP	-	Ionization potential
IVC	-	Independent verification contractor
keV	-	Kiloelectronvolt
kg	-	Kilogram
LANL	-	Los Alamos National Laboratory
lpm	-	Liters Per Minute
MCA	-	Multi-channel analyzer
MDA	-	Minimum detectable activity
meV	-	Millielectronvolt
m	-	Meter
m^2	-	Squared Meters
m^3	-	Cubic meters
mCi	-	MilliCurie
MSHP	-	Manager, Vista Safety and Health Program
mil	-	1/1000 inch
ml	-	Milliliter
mm	-	Millimeter
mR	-	MilliRoentgen
mR/hr	-	MilliRoentgens per hour
mrem	-	Millirem
mrem/hr	-	Millirems per hour
MSA	-	Mine Safety Appliances Company
MSDS	-	Material Safety Data Sheet
MSHA	-	Mine Safety and Health Administration
NaI	-	Sodium iodide
NCA	-	Nuclear Criticality Analysis
NCS	-	Nuclear Criticality Safety
NCRP	-	National Council on Radiation Protection and Measurements
NEA	-	Nuclear Energy Agency
NIST	-	National Institute of Science and Technology

U^{nat}	-	Natural uranium
UR	-	Urine sample
U.S.	-	United States
VISTA	-	Vista Technologies, Inc.
VSHP	-	VISTA Safety and Health Program
VRSP	-	VISTA Radiation Safety Program
WL	-	Working Level
WP	-	Work Plan

NIOSH	-	National Institute for Occupational Safety and Health
n. o. s.	-	Not otherwise specified
NPDES	-	National Pollutant Discharge Elimination System
NRC	-	U.S. Nuclear Regulatory Commission
NS	-	Nose swipe
NTIS	-	National Technical Information Service
NVLAP	-	National Voluntary Laboratory Accreditation Program
OHSO	-	On-Site Health and Safety Officer
ORNL	-	Oak Ridge National Laboratory
ORPO	-	On-Site Ionizing Radiation Protection Officer
OSHA	-	U.S. Occupational Safety and Health Administration
pCi	-	PicoCurie
pCi/gm	-	PicoCuries per gram
pCi/l	-	PicoCuries per liter
P.E.	-	Professional Engineer
PF	-	Protection Factor
PIC	-	Pocket Ionization Chamber
PM	-	Project Manager
PMT	-	Photomultiplier Tube
PPE	-	Personal Protective Equipment
PRP	-	Potentially Responsible Party
PRS	-	Portable ratemeter/scaler
PVC	-	Polyvinyl chloride
QA	-	Quality assurance
QC	-	Quality control
R	-	Roentgen
RA	-	Restricted (radiation) area
rad	-	Radiation absorbed dose
RAS-1 -		Kurz air sampling pump flow calibration kit
REM	-	Roentgen equivalent man
RHSC	-	Radiation Health and Safety Committee
RSO	-	VISTA Radiation Safety Officer
RWP	-	Radiation work permit
SAP	-	Sampling and Analysis Plan
SCBA	-	Self-contained breathing apparatus
SRD	-	Self-reading dosimeter
TODE	-	Total Organ Dose Equivalent
TLD	-	Thermoluminescent dosimeter
TWA	-	Time-weighted average

RADIATION HAZARDS

1 IONIZING AND NON-IONIZING RADIATION HAZARDS

The following Procedure discusses the principles of ionizing and non-ionizing radiation, three types of ionizing and non-ionizing radiation, and human health effects of ionizing and non-ionizing radiation exposure.

1.1 Principles of Ionizing and Non-Ionizing Radiation

An environment is considered radioactive if it contains ionizing and/or non-ionizing radiation at levels that affect the health and safety of workers or the general public. The health effects of overexposure to ionizing and non-ionizing radiation are well defined and can be classified as acute (short-term) or chronic (long-term). Ionizing and non-ionizing radiation health and safety hazards may be classified as having the potential for either external and/or internal exposure. The magnitude of the hazard is partially based on the location of the source radioactive materials and/or radioactive contamination in relation to the exposed individual.

External ionizing and non-ionizing radiation health and safety hazards are posed by ß particles and γ rays and are usually outside of the body. External ionizing and non-ionizing radiation comes directly from the ionizing and non-ionizing radiation source or from contaminated equipment, clothing, or the person himself or herself. External ionizing and non-ionizing radiation exposures may or may not involve physical contact with radioactive materials and/or radioactive contamination. Radioactive contamination is controlled by preventing potential contact or by quickly removing it via personal radioactive decontamination.

Neutrons are a non-ionizing type of nuclear radiation and produce damage to the human body by displacement and/or disruption of chromosomes, Ribonucleic Acid (RNA), Deoxyribonucleic Acid (DNA), atoms and molecules. The displacement/disruption products are harmful to the body. Additionally, neutrons in the body also form neutron activated radioactive isotopes which irradiate essentially all molecules/atoms in the body. Very high neutron doses (such as, from a neutron bomb nuclear weapon) can quickly kill human beings.

Neutrons can be emitted by:

- (α, n) reaction
- (γ, n) reaction
- Spontaneous Fission

All of the above reactions occur in Weapons Grade (WG) Plutonium (Pu). WG Pu consists of 95% Pu-239, other isotopes of Pu and trace amounts of Am-241. Neutrons could be the predominant emissions from some covered (e.g., asphalt) Low Level Waste (LLW) burial sites which have substantial WG Pu mixed in with soil.

The potential for external exposure decreases when one leaves the radiation area immediately or when the source material is removed or adequately shielded. Internal ionizing and non-ionizing radiation exposures result from the entry into the body of radioactive material by inhalation of

Note: For the purposes of this document, Ionizing Radiation includes certain types of Non-Ionizing Radiation.

airborne radioactivity, or through radioactive contamination of the body with radioactive materials by ingestion or dermal absorption of the sources. In addition to ß particle and γ ray emitters, α particle emitters also represent an exposure hazard when deposited internally.

Internal ionizing and non-ionizing radiation exposures refer to radiation from radioactive sources that enter and irradiate the body from inside until it is eliminated or decays radioactively. Protective methods for this type of ionizing and non-ionizing radiation are prevention of entry into the body and elimination of any radioactive material that has entered the body.

Medical procedures, such as the administration of chelating agents, lung lavage, and gastric lavage, may reduce the body's burden of radioactive materials and/or radioactive contamination, although the procedures themselves are risky. Medical intervention to reduce the body's burden of radioactive materials are not recommended, except in extreme exposure situations.

Internal ionizing and non-ionizing radiation exposures continue until the radioactive materials and/or radioactive contamination are eliminated by the body's normal metabolic processes or the material's activity decays to negligible levels. Those radionuclides, such as Lead-210 (^{210}Pb), that are systematically fixed within specific organs of the body (e.g., bone, lung, and thyroid) are greater internal ionizing and non-ionizing radiation health and safety hazards because of their longer residence time within the body before elimination.

Since reducing the body's burden by means other than biological turnover or radioactive decay is impractical, radionuclides, such as ^{210}Pb, with long half-lives that remain in the body for long periods of time (i.e., 1 year) are considered very hazardous to human health. All such exposures should be avoided, and preventive ionizing and non-ionizing radiation protection practices and work methods and appropriate Personnel Protective Equipment (PPE) should be used to preclude exposure.

The type and quantity of radioactive materials at Vista project work sites are determined through a site history and current surveys. Activities at operating facilities are regulated under federal or state authority, and the presence of radioactivity is usually documented in current site files. Radiological conditions may not be well known at facilities that are abandoned, have had marginal maintenance, or have had limited surveillance.

At VISTA project work sites where ionizing and non-ionizing radiation health and safety hazards are known or suspected to be present, assistance will be sought from the Vista Radiation Safety Officer (RSO) in preparing the Quality Assurance Program Plan (QAPP). Prior to the start of a Vista project, Vista and client personnel will discuss the types and amounts of exposure anticipated to be encountered in the performance of the work.

The RSO will decide on specific criteria and procedures appropriate to the VISTA project, including the selection of the Vista On-Site Radiation Protection Officer (ORPO) and On-Site Health and Safety Officer (OHSO). Any conclusions by the Vista RSO will be recorded by letter between the cognizant parties. Any ionizing and non-ionizing radiation health and safety hazards and procedures for the evaluation and control of ionizing and non-ionizing radiation hazards will be detailed in the applicable Health and Safety Plan (HSP).

Note: For the purposes of this document, Ionizing Radiation includes certain types of Non-Ionizing Radiation.

Airborne radioactive particulates can be inhaled or ingested into the body. Radioactive particulates may also enter the body through cuts and abrasions, i.e., injection. With the exceptions of tritiated water, certain radio-organics used in research, and certain radiopharmaceuticals, radioactive materials are not absorbed significantly through the skin. Exposed skin that has dermatitis, abrasions, or cuts will absorb radioactive materials more easily than intact skin.

Once the presence of specific radioactive materials and/or radioactive contamination is established, comparing field measurements to applicable federal standards and guidelines will assess the hazard. The regulatory basis for limits for exposure to ionizing and non-ionizing radiation are found in the International Commission on Radiological Protection (ICRP) publication 26, "Recommendations of the International Commission on Radiological Protection," and ICRP publication 30, "Limits for Intakes of Radionuclides by Workers."

As adopted by 10 CFR 20, these guidelines are as follows:

- Annual Limit on Intake (ALI) - "The quantity of a single radionuclide which, if inhaled or ingested in 1 year, would irradiate a person, represented by reference man (ICRP Publication 23) to the limiting value for control of the work place"; and

- Derived Air Concentration (DAC) - "Quantity obtained by dividing the ALI for any given radionuclide by the volume of air breathed by a reference man during a working year." The DAC for a given radionuclide is a derived limit and is the activity concentration of that radionuclide in air in activity per volume of air, which, if breathed by a reference man would result in a concentration that, for 2000 hours of air emission, would lead to irradiation of any body organ or tissue to the appropriate limit. It is expected that the ICRP recommendations will be adopted shortly by Occupational Safety and Health Administration (OSHA).

1.2. Types of Ionizing and Non-Ionizing Radiation

When the coulombic forces (repulsive forces due to the positive charges of protons) are sufficient to overcome the nuclear forces (that hold the nucleus together, also known as "nuclear glue"), excess energy is emitted from the nucleus in the form of electromagnetic waves or rays and/or high velocity particles.

Three types of radiation are of major concern:

- α particles - Particles consisting of two protons and two neutrons bound together with an electrical charge of plus 2. α particles are identical to helium nuclei that have a large amount of translational (kinetic) energy.

- ß particles - Particles with a single electrical charge and high kinetic energy. ß particles, when negatively charged, are identical to electrons.

Note: For the purposes of this document, Ionizing Radiation includes certain types of Non-Ionizing Radiation.

- γ rays - High energy, short wavelength, electromagnetic radiation. Other types of electromagnetic radiation include visible light, ultraviolet light, and radar.

After the emission of an α particle or ß particle (but not γ ray radiation), the original atom is transformed or transmuted into an atom of a different element called a daughter product. The daughter product may or may not be radioactive.

By the process of ionization, ionizing and non-ionizing radiation interact with the electrons surrounding the nucleus of the atoms or molecules that compose the material through which the ionizing and non-ionizing radiation is traveling. This process creates ion pairs, positively charged atoms or molecules and electrons. Through a series of many ionizing and non-ionizing radiation interactions, each consuming an average of about 33 electron volts per ion pair, the ionizing and non-ionizing radiation loses its initial energy. In the case of α and ß particles, this occurs after loss of all velocity.

If an α particle picks up two electrons, it becomes a helium atom. An electron loses its velocity (kinetic energy) and becomes a free electron. γ ray radiation is eventually degraded and finally absorbed.

The various types of ionizing and non-ionizing radiation differ in their ability to penetrate matter as shown below.

Table 1-1 - Energy of Ionizing and Non-Ionizing Radiation

Type of Radiation	Distance Traveled in Air	Ion Pairs In 1 Centimeter of Air	Shielding
α particles	Less than 1 inch	Hundreds	A sheet of paper
ß particles	Several inches	Hundreds	1/16 inch of aluminum foil
γ Rays	Hundreds of feet	1 to 2	2 feet of solid aluminum

1 Millielectronvolt (meV)

1.3. Human Health Effects of Ionizing and Non-Ionizing Radiation Exposure

There are two principle mechanisms by which ionizing and non-ionizing radiation interact with living tissue. The first is the direct effect where the energy of ionizing radiation is transferred directly to the molecule of interest, and the second, the indirect effect where the directly affected molecule transfers its energy to another molecule. In biological systems, the direct effect is usually chromosomal damage while the indirect effect is radiolysis of water and then oxidation, the formation of Hydrogen Peroxide (H_2O_2) and free radicals throughout the body.

Ionizing radiation interacts with atoms in the body in the same way that it does with all other matter, that is, by ionization. The effect of ionizing radiation in living tissue is generally assumed to be almost entirely due to the ionization process that destroys the capacity for reproduction or division in some cells or causes mutation in others. The human body constantly produces new cells

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to replace those that have died or been damaged. The body has the capability for repairing cell damage. In order to survive, cell damage must be kept within the capabilities of the body's repair system.

Ionizing radiation strips electrons from atoms and breaks chemical bonds between atoms. A simple molecular structure, such as water, will recombine after ionization. This, however, is not the case in a complicated living cell. Here, ionization may give many possible atomic combinations. The rupture of a few bonds in the elaborate structure of the molecules of the living cell appears to be particularly sensitive.

The term "dose" is generally used to express a measure of ionizing and non-ionizing radiation that a body or other material absorbs when exposed in a radiation field. Radiation field is defined as the intensity of the ionizing and non-ionizing radiation to which a body or material is subjected. The effects of radiation can be somatic, i.e., injury to the individual and/or genetic, i.e., changes passed on to future generations.

Radionuclides that have entered the body through inhalation or ingestion, present a special hazard. Once inside the body, the radionuclides are absorbed, metabolized and distributed throughout the tissues and organs according to their chemical properties. Their effects on organs or tissues depend on the type and energy of the ionizing and non-ionizing radiation and residence time within the body. The following sections discuss somatic health effects and genetic health effects of exposure to ionizing and non-ionizing radiation.

1.3.1 Somatic Health Effects

Somatic health effects are biological effects of ionizing and non-ionizing radiation that are expressed in the exposed individual. The somatic health effects of radiation can be divided into prompt effects and delayed effects. Prompt effects are observed shortly after an individual receives an acute ionizing and/or non-ionizing radiation dose, (e.g., a very large dose received in a very short time period).

Prompt health effects are associated with a threshold, e.g., if the ionizing and/or non-ionizing radiation dose is below a certain level, no effect is noticed, but if the dose exceeds that level, most people suffer an effect. Delayed effects can result from an acute ionizing and/or non-ionizing radiation dose, and are the major effects of a chronic radiation dose. A chronic radiation dose is continuous or repeated exposure of an individual to ionizing and non-ionizing radiation at low dose rates over a long period of time. The biological effects of whole-body ionizing and non-ionizing radiation exposures are presented in the table below.

Note: For the purposes of this document, Ionizing Radiation includes certain types of Non-Ionizing Radiation.

Table 1-2 - Biological Effects of Whole-Body Ionizing and Non-Ionizing Radiation Exposures

Type of Exposure	Quantity (mrem)	Biological Effects
Jet plane travel	1	Currently, the amount of low level radiation a person receives can be measured, but cannot be related to the effects on the body.
Television	1	Because this data is inclusive, the effects of low level radiation are assumed to be directly related to the total amount received.
Food, Water, Air	25	100 cases of cancer per million persons exposed. Lifetime dose.
Housing Wood	35	100 cases of cancer per million persons exposed. Lifetime dose.
Housing Brick	45	100 cases of cancer per million persons exposed. Lifetime dose.
Housing Stone	50	100 cases of cancer per million persons exposed. Lifetime dose.
Chest x-ray	50	100 cases of cancer per million persons exposed. Lifetime dose.
Dental x-rays	80	100 cases of cancer per million persons exposed. Lifetime dose.
Gastrointestinal tract x-ray	210	100 cases of cancer per million persons exposed. Lifetime dose.
Lifetime dose from natural background radiation.	10,000	No effect on normal life spans. Natural back ground radiation of 300 mrems per year

Table 1-3 - Biological Effects of Whole-Body Ionizing and Non-Ionizing Radiation Exposures (Cont'd)

Type of Exposure	Quantity (mrem)	Biological Effects
Accidental exposure to Co-60 Source(s), or flash X-ray machine or similar nuclear incident	25,000	Radiation effects detectable only by laboratory examination; decrease in white blood cells and platelets if background information is available prior to exposure.
Accidental exposure to gamma or neutron beam	50,000	Possible radiation sickness; headache; dizziness; malaise; nausea; vomiting; diarrhea; decrease in blood pressure; irritability and insomnia.
Accidental exposure to weapons effect simulator	100,000	Possible radiation sickness; little or no life shortening.
Criticality Accident or similar nuclear incident; high radiation zones, e.g., nuclear cleanup	250,000	Acute radiation sickness; few or no deaths and significant life shortening. Radiation sickness includes vomiting, diarrhea, loss of hair, nausea, hemorrhaging, fever, loss of appetite and general malaise. Recovery (if no complications) is about three months.
Critically Accident - Exposure to high radiation areas, e.g., Chernobyl	450,000	Half of those exposed will die within 30 days. Recovery with some permanent impairment of the other 50 percent.
Critically Accident - or exposure to nuclear weapon blast	1,000,000	Death within 30 days.

mrems = Millirems

Note: For the purposes of this document, Ionizing Radiation includes certain types of Non-Ionizing Radiation.

1.3.2 Genetic Health Effects

Chronic effects may result from long-term exposures (many years) to levels of ionizing and non-ionizing radiation below the acute lethal dose (less than 450 rems.) These effects include induction of cancer and genetic mutations. Based on recent research, an external γ ray dose of 15 rems would increase the potential of dying from cancer by approximately 1-percent. The same dose, if due to α particles in the lungs, would also result in approximately a 1- percent increase in the chance of dying of lung cancer.

The average person receives an ionizing and non-ionizing radiation dose of approximately 0.30 rem per year from natural sources and medical tests. No significant effects have been demonstrated in people at dose rates of less than 5 rems per year.

Note: For the purposes of this document, Ionizing Radiation includes certain types of Non-Ionizing Radiation.