I. INTRODUCTION TO ATOMIC PHYSICS

A. Nature of Matter

Molecules - when matter is subdivided, the smallest particle possessing all the original physical and chemical properties.

Atom - the molecule may be subdivided into separate components called atoms.

Nucleus - every atom has a basic center called the nucleus, where subatomic particles are found, the protons and neutrons.

Electron - a stable elementary particle, having a charge of minus one (-1) and found orbiting around the nucleus.

Nuclear reaction - the interaction of a stable or radioactive atoms and some energetic particle, in such a manner that the nucleus of the atom is affected.

Isotope - elements which have the same number of protons in the nucleus but different number of neutrons and therefore differ in mass number.

Nuclear stability - generally, an isotope is said to be stable (non-radioactive) if the neutron-proton ratio (n/p) is greater than or equal to one (1). The n/p ratio ranges from 1 for lighter nuclei to 1.5 for heavier nuclei. Example: Carbon-14 is a radioactive isotope because there are 8 neutrons and 6 protons in its nucleus (ratio = 1.33). Carbon-12 is a stable isotope because there are 6 neutrons and 6 protons in its nucleus (ratio = 1.0).

Nuclear decay - the ability of isotopes (radioactive) to emit particles through a natural occurrence. In some cases new elements are formed by this decay, and in some cases only energy is emitted. Examples of the most common type (alpha, beta, and gamma) decay follow. The fourth type of decay is the production of a new element through positron decay. This is the process of a nucleus emitting a particle with the same mass as an electron, but with a positive charge (+).

B. Production of Radioactive Isotopes:

Up to 1934, scientists discovered natural occurring elements number 1 (Hydrogen) through 92 (Uranium). Starting in 1934, physicists began to make artificial radioactive elements in accelerators or "atom smashers". The target nucleus was bombarded by accelerated particles (deuterons, protons, alpha). The resulting nucleus was an artificially produced element.

P^{31} + deuteron = P^{32} + proton
V^{51} + proton = Cr^{51} + neutron
F^{19} + alpha = Na^{22} + neutron

In all charged particle reactions, the bombarding particle (D^2, p+, or α^4) must have very high energy. Both the target and bombarding particle were positively charged. Since like charges repel, the bombarding particle had to have sufficient energy to overcome the repulsion of like charges and this is what necessitated the acceleration of the bombarding particle.

When the discovery of neutrons and neutron capture was revealed, a whole new series of isotopes became available.

P^{31} + neutron = P^{32} + gamma
S^{34} + neutron = S^{35} + gamma
Co^{60} + neutron = Co^{60} + gamma

With the construction of nuclear reactors, vast quantities of neutrons became available for "nuclear transmutation". At present, there are over a thousand isotopes which can be produced through the use of nuclear reactors.

During the early 1940's, scientists were completely involved with war effort, and from this effort came forth a series of isotopes which never before existed. These isotopes are called "Transuranic Elements". The Transuranic Elements do not exist in nature and are "man-made". The artificial elements which have been produced range from the last of the naturally occurring ones (Uranium, number 92 is the heaviest natural nuclei) up to number 105. Recently, elements number 106 and 107 have been synthesized, and it has been postulated that production of elements beyond number 121 is possible. A total of approximately 100 new isotopes have been produced and identified as "synthetic" elements. Some of these more commonly recognized are:

$_{93}Np^{237}$ $_{94}Pu^{238}$ $_{94}Pu^{239}$ $_{95}Am^{241}$ $_{96}Cm^{242}$ $_{98}Cf^{252}$, etc.

C. Industrial Applications:

Industrial labs are constantly seeking new techniques to improve the control and evaluation functions of specific applications. New and sophisticated methods have been developed to lower production costs, improve products, and provide solutions to problems heretofore unapproachable. The nuclear tool has saved millions of dollars in the nondestructive testing field alone. A few of the applications are listed below with brief explanation.

1. Gamma Irradiation - treating food stuffs in such a manner that deterioration and spoilage is reduced considerably.

2. Mixer evaluation - to determine the relative mixing capability of certain mixing machines, short lived isotopes are introduced so results can be obtained and the isotope will have decayed away by the time the products reach the consumer.

3. Interface marking:

   Some petroleum pipelines may carry many different products. Radioactive tracers are used at the interface of different products. Now an operator is signaled by a detector when a new material is entering the system and a change over can be made with very little loss of the preceding batch.

4. Level gaging:

   Suppose a company wants to monitor the level of cooking molasses in a large tank. Sight tubes and windows are not suitable as the material is too viscous to drain, and internal floats gum up and stick. Therefore, the best method applicable to this situation is external monitoring.

   A typical gaging system would consist of a gamma detector and a Co-60 or Cs-137 source traveling in a track system on opposite sides of the tank. The detector signal depends on whether gamma rays from the source pass through the molasses or the air. As the source and detector rise from the bottom of the tank, at the same rate, an increase in counting rate would indicate the liquid level.

5. Wear measurement:

   A motor manufacturer wished to know the wear rate of his piston rings. A crude method would be to disassemble the motor and do definite measurements on the ring. By utilizing the iron in the piston ring, the ring is made radioactive by induction into a reactor. Fe-59 isotopes are produced. The ring is inserted on the piston and the motor reassembled. Continuous running of the machine would cause minute particles of radioactive iron to wear off into the lubricating oil. Due to the extreme high sensitivity, (one part in 10 million), which can be detected, the total amount of wear can be determined as a proportion to the increase in radioactivity in the lubricating oil.

6. Radiography:

   To replace the X-ray machine, a costly oversized and fixed instrument used in nondestructive testing (NDT), persons concerned about field application of NDT developed gamma radiography. A nuclear source 1/4" x 1/4" containing 100 curies of activity is introduced into areas where X-ray machines were never able to radiograph. When mounted on a flexible cable, the source is transported in a shielded "camera" utilizing a light, portable system with its own built-in power supply. Examination of complex piping mazes can be accomplished where integrity of weld areas is an absolute must.

7. Oil Well Logging:

   In the petroleum industry, core sampling, a very tedious and time consuming method, was used to determine the strata of possible oil bearing areas. When nuclear sources were introduced, the coring method, while still used, was mostly replaced by nuclear logging which is a much faster and more economical method. A neutron source is introduced into a well casing by a flexible cable. From the source are emitted fast neutrons. The principle here is to determine the hydrogen content of the strata. If hydrogen is present and the neutrons enter this hydrogenous area, they are slowed down considerably and scattered back to the well casing. The neutrons become slow neutrons by virtue of their lower energy. The ratio of fast to slow neutrons is a good indication of the quantitative value of hydrogen present. This method is sufficiently sensitive to distinguish between water and oil.

8. Spacecraft Gas-gauge:

   One very unique application of radioisotopes is the application of a fuel gauge on the Apollo and Saturn spacecrafts. A standard fuel gauge normally operates by measuring the height of a confined liquid. This type of gauge fails in the weightlessness of space as the liquid fuel breaks up into globules and floats around the tank. With nuclear gauging system (a row of detectors and gamma sources placed on opposite sides of the tank), a measurement can be made of the remaining fuel in the tank. This measurement method is not dependent upon how the fuel is distributed.

II. FUNDAMENTAL CONCEPTS OF RADIOACTIVITY

A. Radioactivity: An element is said to be radioactive if it can spontaneously decay or be transformed into another element. This transformation is always accompanied by emission of nuclear radiation. The same element can occur in either a radioactive or a stable form. These variations of the same element are called isotopes. Isotopes of the same element have the same atomic numbers (Z numbers) but different mass numbers (A numbers). That is, the same number of protons but a different number of neutrons. Therefore, Pb^{206}, Pb^{207} and Pb^{208} are all isotopes of the same element, lead. All isotopes of the same element have the same chemical properties whether they are radioactive or stable.

B. Characteristic Particles: The spontaneous radiation emitted by the radioactive elements are generally Alpha, Beta and Gamma. Other radiation such as X-ray and Neutron must be induced and will be considered briefly.

1. Alpha Particles have a mass equal to that of the helium nucleus and are shot out with a velocity about one-tenth that of light, and have a positive charge of two (2). They possess great ionizing power but relatively little penetrating power - only a few centimeters in air at atmospheric pressure.

2. Beta Particles consist of negatively charged particles moving with varying speeds. The penetrating power of the beta particle depends upon the speed of the particle. Those which move most rapidly possess the greatest penetrating power. Generally, 2 cm of aluminum stops all beta particles.

3. Gamma Rays are electromagnetic radiations originating from a radioactive isotopic elemental transition. They have no charge but possess great penetrating power. They present special health problems because of their deep penetration and high energy disposition. Dense materials are required to effectively shield gamma radiation.

4. Neutrons are elementary nuclear particles with a mass approximately the same as that of a hydrogen atom and electrically neutral; its mass is 1.008982 atomic mass units (amu). Neutrons are commonly divided into subclassifications according to their energies as follows: Thermal, around .025 eV (electron-volts); Spithermal, 0.1 eV to 100 eV; Slow, less than 100 eV; Intermediate, 0.5 eV to 10 KeV; Fast, greater that 0.1 MeV. They are easily shielded with paraffin or hydrogen containing materials.

C. Detection of Radiation:

1. Ionization Counter - an ionization chamber in which a delimited beam of radiation passes between the electrodes without striking them or other internal parts of the equipment. The electric field is maintained perpendicular to the electrodes in the collecting region; as a result, the ionized volume can be accurately determined from the dimension of the collecting electrode and the limiting diaphragm.

2. G-M Counters - Geiger-Muller counters are another type of gas-filled detector. In the G-M detector, a gas-filled chamber is fitted with a collecting electrode, which produces a signal when the chamber is exposed to a radiation field. At higher operating voltages, gas multiplication causes complete breakdown and involvement of the entire collecting electrode (discharge), even if only a single ion pair is formed. The device has a relatively lengthy dead-time and the pulse amplitude is not dependent on the energy deposited.

3. Scintillation detectors - A thallium-activated sodium iodide (NaI) crystal is the most common detection device. The crystal emits a flash of high energy light upon the absorption of gamma radiation, which is captured and amplified by an attached photomultiplier (PM) tube. The emerging electrical pulse is of short duration and its amplitude proportional to the energy absorbed. When coupled with suitable electronics, the scintillation detector not only provides accurate and rapid detection of gamma fields, but can also be used to quantify the unique spectra of each radioisotope. Spectrum analyzers are valuable for use in determining both the amount and identification of unknown sources of radiation.

4. Semiconductor detectors - For gamma-ray detection and energy measurement, the germanium-lithium, or Ge(Li), counter is used. The Ge(Li) detector provide very precise spectral information. These detectors are stored and operated at cryogenic temperatures, normally in a liquid nitrogen bath.

5. Some types of equipment used by Cardinal are described as follows:

a) Precision Model 107C, Gamma 150 and Ludlum 4 are portable, battery operated radioactivity survey and counting meters, sensitive to gamma and medium energy beta radiation. These instruments have three full scale ranges. These meters shall be calibrated every six months.

b) The Model 2600 Ludlum Spectrometer is a general purpose nuclear counting instrument. The unit features preset count or time with background subtract capabilities.

c) Pocket Dosimeters - Direct reading Pocket Dosimeter reads instantaneously the total accumulated dosage. The Dosimeter is designed for detection and measurement of X and gamma radiation only. Pocket dosimeters should be worn by the person handling radioactive materials if the radiation dose exceeds 20 mR/hr at one meter.

d) Film Badge Service - Light-weight plastic holder contains a slide-in film packet that is evaluated monthly. The use of ultrasensitive films and exclusive evaluation techniques make it possible to provide accurate evaluation of even very low doses. X, gamma and beta radiation can be detected by this means.

e) The Nucleus Spectrum 88 is a NaI scintillation detector coupled with a computerized spectrum analyzer. This device is used to determine the nature of samples of unknown isotopes, and for tracer quality control purposes.

f) Field measurements of radioactivity below the surface of the Earth are accomplished by specialized down-hole instruments. The company uses only NaI scintillation measuring equipment.

D. Measurement of Activity:

1. Curie - That quantity of a radioactive nuclide disintegrating at the rate of 3.700×10^{10} atoms/second. Abbreviation: Ci.

   a) Microcurie - one millionth of a curie ($3.7 \text{ X } 10^4$ disintegrations per second). Abbreviation: µCi.

   a) Millicurie - one thousandth of a curie ($3.7 \text{ X } 10^7$ disintegrations per second). Abbreviation: mCi.

2. Roentgen (R) - An exposure dose of X- or gamma-radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air, ions carrying one electrostatic unit (esu) or quantity of electricity of either sign.

3. Rad (written: rad) - The unit of absorbed dose, which is 100 ergs/per gram (0.01 J/Kg) in any medium. The rad is a measure of the energy imparted to matter (i.e., retained by matter) by ionizing radiation per unit mass of irradiated material at the place of interest.

4. RBE (Relative Biological Effectiveness) - The RBE is a factor which is used to compare the biological effectiveness of absorbed radiation doses (i.e., rads) due to different types of ionizing radiation. More specifically, it is the ratio of an absorbed dose of X-rays or gamma rays to the absorbed dose of a certain particular radiation required to produce an identical biological effect in a particular experimental organism or tissue. This ratio is sometimes called the Relative Biological Efficiency Factor.

5. Rem (Roentgen Equivalent Man) - The rem is the unit used to express human biological doses as a result of exposure of one or many types of ionizing radiation. The dose in rems is equal to the absorbed dose in rads times the RBE factor of the type radiation being absorbed. Thus, the rem is the unit of RBE dose.

E. Technical Aspects of Any Isotope:

1. Half-Life - All radioactive isotopes have a special property associated with them, known as the *half-life*. Half-life is the time required for the activity of a given radioactive species to decrease to half of its initial value due to radioactive decay. The biological half-life is the time required for the amount of a specified element which has entered the body (or a particular organ) to be decreased to half of its initial value as a result of natural, biological elimination processes. The effective half-life of a given isotope is the time in which the quantity in the body will decrease to half as a result of both radioactive decay and biological elimination.

2. Energy of Emission - All isotopes have definite amounts of energy associated with each particle coming off. These energies are characteristic of the isotope.

3. Effect of Distance - Generally speaking, the greater the distance from the source of radiation, the less the dose received by personnel. The intensity of radiation is diminished by an inverse square relationship with distance. A source measuring an intensity of 10 mR at a distance of one foot would measure 100 mR/5^2 at a distance of five feet; in other words, a radiation dose of 4 mR at the five foot distance.

4. Shielding of Various Materials - A shield can be any material or obstruction which absorbs radiation and, thus, tends to protect personnel or materials from the effects of nuclear radioactivity. Alpha particles, for example, can be shielded with a piece of paper. Beta particles can generally be absorbed through 2 cm of aluminum. Gamma rays, however, are the most penetrating and dense shielding materials must be employed to reduce radiation.

5. Stay Time - The period during which personnel are allowed to remain in a radiation and/or contaminated area before accumulating their permissible dose.

6. Inverse Square Law - A general property of physics which states that if the distance from a point is doubled, the radiation at the second point will be 1/4 of the radiation which is present per unit area at the first point.

$$\frac{R_1}{R_2} = \frac{(d_2)^2}{(d_1)^2}$$

III. BIOLOGICAL EFFECTS OF RADIATION

A. Characteristics of radiation:

1. Ionization in Tissues - Radiation in tissues varies in relation to the energy of the radiation, the absorbed dose, the time span over which the dose was received, the amount of body area irradiated, plus other factors not so well defined. Ionization of the atoms which make up the chemical constituents of the tissue cells, as the result of interactions with the incident radiation, is probably the basic cause of injury. Irradiation within the cell can result in death of the cell, complete destruction of the cell's ability to reproduce, partial, incomplete, or faulty function (as of glandular cells) as well as production of genetic mutations.

2. Radiosensitivity of Tissue - Various types of tissue respond quite differently to a given kind and dose of radiation. Generally speaking, the following may be accepted as a list of common cells and/or tissues in the order of decreasing radiosensitivity:

   a. Lymph tissue (Cells of the body fluid).

b. White blood cells and immature red blood cells in the bone marrow.

c. Cells lining the gastro-intestinal tract.

d. Cells of the reproductive organs.

e. Skin.

f. Blood vessels and body cavity lining.

g. Tissue of the liver and adrenal glands.

h. Other tissues, including bone, muscle, and nerves.

3. Time Factor vs. Total Dose - The biological effect of radiation depends not only on the total amount absorbed (dose), but also on the rate of absorption (dose rate). For example, 600R would probably be fatal to a man if it were absorbed by the whole body within a period of one day; but would probably have no noticeable effect if absorbed over a period of 30 years because the body tissue is able to recover when the dose rate is low. Effects of radiation which appear within approximately a month are termed acute effects. This includes the immediate (0 to 48 hours) and the delayed (1 to 5 weeks) effects. Chronic effects would include these which result in persistent changes (such as radiation dermatitis), vascular or atrophic changes, and long term effects (appearing after one year such as tumor induction or cataract formation).

B. Radiation Doses to be Considered in Normal Safety Precautions:

1. Acute Effects of Whole-Body Penetrating Ionizing Radiation on Human Beings

Dose in Less Than One Week (R)	Effects
0 - 150	No acute effects other than blood changes. May be a serious long-time hazard.
150 - 250	Nausea and vomiting within 24 hours. Minimal incapacitation after 2 days.
250 - 350	Nausea and vomiting in under 4 hours. Some mortality will occur in 2 to 4 weeks. Symptom free period 48 hours to 2 weeks.
350 - 600	Nausea and vomiting likely before 2 hours. Mortality probable in 2 to 4 weeks. Incapacitation prolonged.
Greater than 600	Nausea and vomiting almost immediately. Mortality in 1 to 2 weeks.

2. Occupational Dose Limits for Adults

Except for planned special exposures, the occupation dose limits for adults are as follows:

a. An annual limit, which is the more limiting of:

(i) the total effective dose equivalent being equal to 5 rems, or

(ii) the sum of the deep dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50 rems.

b. The annual limits to the lens of the eye, to the skin, and to the extremities which are:

(i) an eye dose equivalent of 15 rems, and

(ii) a shallow dose equivalent of 50 rems to the skin or to any extremity.

C. Safety Precautions. Generally, the following safety facts should be known and observed:

1. Safety Through Distance - Distance can be an effective safety measure from a source. Safe distances should be known for the amounts of radioactive material being handled.

   Examples of exposure rate at various distances from a 100 mCi source:

Distance:	3 feet	6 feet	9 feet
Radioactive Material	mR	mR	mR
Ir^{192}	61	15.25	6.8
I^{131}	25	6.25	2.8

2. Safety Through Shielding - Certain materials are active shields against radiation. The half-layer value is the amount of shield necessary to reduce the radiation to one-half the value.

   Half-layer value for some common materials:

Radioactive Material	Lead	Steel	Concrete
Co^{60}	0.49"	0.87"	5.0"
Cs^{137}	0.25"	0.68"	2.1"
Ir^{192}	0.19"	0.5"	1.9"

3. Safety Through Stay Time - The safety of an individual may be gained by controlling the amount of time he is exposed to radiation. If exposure attains an unsafe limit, personnel should be rotated.

IV. HEALTH PHYSICS REGARDING ACTUAL FIELD STUDIES

A. Monitoring Job Site Before Initiation of Work

1. Use a low level survey meter to monitor the area before initiation of work. Record observations on a sketch of the area (use supplied Area Well-head Survey Form).

2. Certify that the area is clean before commencing the job.

B. Handling Equipment - The following items shall be worn at all times when handling radioactive material while health physics problems are present:

1. Gloves*
2. Face Masks**
3. Handling Tongs*
4. Protective Clothing*

* These items will always be worn while handling radioactive materials, thus, preventing the possibility of contamination to the person who is actually handling radioactive material.

** Face masks shall be worn at all times when a dangerous radioactive material is being used in a field study. The face mask shall be a type approved by the National Bureau of Mines and should contain an excellent organic filter agent (activated charcoal or equivalent). Gas and Oil tracer material require the use of sealed, canister type face masks.

C. Pocket Dosimeters - can be worn by personnel who are handling the radioactive materials. If, however, personnel also carry personal film badges, then the pocket dosimeter is optional. The advantage to the pocket dosimeter is that it is direct reading. If the radiation level is not excessive (generally 1 to 10 mCi of Iodine 131 will be handled per study), then it should be the option of the Radiation Safety Officer whether pocket dosimeters are required.

D. Film Badges - It is mandatory that all personnel working in a restricted area (an area greater than 2 mR/hr) wear a film badge. This includes all job site activities as well as transportation of radioactive materials.

E. Tracer Packaging - All packages containing radioactive materials from a supplier shall be monitored prior to their leaving the supplier's facilities. The dosage limits shall comply to the ICC shipping regulations which are: a maximum of 200 mr/hr at the surface of a shipping container and a maximum of 10 mr/hr at a distance of one meter from the surface of the container. Other regulations may apply.

F. Handling and Field Equipment Check List - The specific application may require additional radiation detection equipment other than that listed below, but, generally, field equipment will consist of the following items:

First aid kit.
Kim-Wipes (Industrial Type).
Sponges.
Large and small plastic storage bags for containing contaminated equipment, sponges, etc.
Protective clothing.
Two remote handling tongs.
Masking and plastic electrical tape.
Plastic wash bottles.
Rubber Gloves (disposable vinyl).
Labels for the return of radioactive waste.
Film badges.
Concentrated wash solution.
Low level survey meter.

G. Operating Procedures
   1. Pre-job knowledge and planning - the Radiological Safety Supervisor (field location supervisor) must know:

      a. Types of radiation involved.
      b. Intensity of radiation.

c. Relative hazard of each type of radiation.
d. What the "stay time" (maximum allowance exposure time) is.
e. What the possible contamination problems are.
f. Any internal contamination problems.
g. What industrial nuisance removable contamination will create.
h. What controls must be dictated to protect personnel.
i. Methods for controlling access to radiographic areas.

2. Specific Procedures will vary with the individual job applications. In general, the following procedures should be followed:

   a. Plan the job in advance.
   b. Monitor the area and measure the background radiation level.
   c. Optimum handling location should be selected. Radioactive material should be handled in a sheltered area, as far from affected personnel as practical (remember ALARA).
   d. Define the area which is prohibited to unauthorized personnel. (2 mr/hr is the maximum allowable radiation to people not wearing film badges).
   e. Handle radioactive material with special consideration given to splashing, wind conditions, and any other outside influence which could interfere with the safe handling of the material.
   f. Plastic or rubber gloves should be worn at all times while handling radioactive materials. If windy conditions exist, goggles and respirator should be used.
   g. Exposure time should be controlled. If exposure approaches the maximum permissible limit, personnel should be rotated.
   h. Allow no eating, smoking, or drinking in the restricted area.
   i. Following the completion of the operation, the entire area should be monitored.
   j. Area Well-head Survey Sheet should be filled out and given to customer.

H. Oil Field and Plant Tracer Applications

Selection of the isotope depends on the study to be performed. Critical isotopes are:

Iodine - I^{131}	Scandium - Sc^{46}
Iridium - Ir^{192}	Antimony - Sb^{124}

The method of injection depends on the type equipment available and the pressure and condition of the well. Following are descriptions of known techniques:

1. Liquid and gas tracers can be inserted by means of a sampling bomb. Pressure is applied to the bomb and the material is forced into the well head. This method is sometimes used on gas wells and on geothermal wells. Cardinal rarely uses this method.

2. Materials are placed in breakable vessels and attached to a logging device. When in the well, they are exploded by use of a squibb charge. Cardinal has never used this method.

3. Material can be poured or inserted by using a syringe directly into the well head. Used where no pressure is involved. Cardinal occasionally uses this method, especially for braiden head tracers.

4. Where fracture stimulation of oil wells is concerned, the fracture proppant (sand) is generally mixed with the frac fluid at the blender. Radioactive sand can be poured into the blender by hand. This is referred to as a "hand-tag" and is a method Cardinal rarely uses.

5. A sample bomb is lowered into the well end by using a turning device attached to a solenoid. Material is released into the flow. Cardinal never used this method.

6. An appropriate amount of the isotope is added to an injection tool which is controlled from the truck panel electronics, permitting limited quantities of material to be injected from the tool in a controlled fashion. The injection tool is commonly referred to as an ejector tool. Cardinal's ejector tool utilizes a micro-processor controller to accurately control the shot size. This is the method which is used for most field tracer studies, except for well stimulation treatments.

7. The Cardinal Surveys Company patented Tagmaster® unit is used to inject controlled amounts of proprietary sealed tracer beads into a stimulation treatment. The material is injected via a high-pressure hose and tee directly into the stimulation line, down-stream of any stimulation pumping company's equipment.

Studies covered are: acidizing operations, fracture stimulation treatments, cement top locations, cement channel locations, casing shoe channel locations, water flood directional flow, oil production profiles, gas flooding, recovery projects, refinery and cake determination and permeability surveys. The material is also used in checking the flow of alumina catalyst in refineries.

I. Field Service Equipment - TAGMASTER® Units

1. No changes or modification of equipment (or parts for equipment that differ from original parts) will be made without prior approval.

2. Preventive maintenance will be performed and recorded on a regular monthly basis.

3. Compartments will be locked at all times of non-use.

4. Regulation placards will be affixed to four sides of vehicles and will be maintained and replaced as needed.

5. All rig up equipment will be cleaned and checked for wear after each job is completed.

6. Line monitor will be used on each job. A lap-top computer system is provided for this purpose. Note that some stimulation company rig-ups prevent placement of the line monitor probe.

7. Portable gamma detection equipment will be calibrated every six (6) months.

8. Radioactive material will be transported in accordance with regulations of the Department of Transportation.

9. Radioactive decontamination of equipment will be performed by hand, using safety equipment provided. The Tagmaster® units will be cleaned only at the well site or at the District. Radioactive waste will be placed in plastic bags, labeled as "Radioactive Waste" and disposed in the appropriate container at the Odessa Lab. The Tagmaster® unit will not be washed in the district wash-bay, unless the unit has been surveyed and approved clear of loose radioactive material.

10. The TAGMASTER® unit is strictly for customer service. Personal use is prohibited.

J. Field Service Equipment - Logging Units

1. No changes or modification of equipment (or parts for equipment that differ from original parts) will be made without prior approval.

2. Preventive maintenance will be performed and recorded on a regular monthly basis.

3. Compartments will be locked at all times of non-use.

4. Regulation placards will be affixed to four sides of vehicles and will be maintained and replaced as needed.

5. All rig up equipment will be cleaned and checked for wear after each job is completed.

6. Portable gamma detection equipment will be used to survey each well location before and after a tracer study.

7. Radioactive material will be transported in accordance with regulations of the Department of Transportation.

8. Radioactive decontamination of equipment will be performed by hand, using safety equipment provided. The units will be cleaned only at the well site or at the District. Radioactive waste will be placed in plastic bags, labeled as "Radioactive Waste" and disposed in the appropriate container at the Odessa Lab. The logging unit will not be washed in the district wash-bay, unless the unit has been surveyed and approved clear of loose radioactive material.

9. The logging unit is strictly for customer service. Personal use is prohibited.

K. Emergency Procedures

Emergencies vary greatly in their perspective hazards. Sometimes these emergencies are in the form of spills, fires or explosions which result in the spread of radioactive contamination. Emergency procedures contained in the National Bureau of Standards, Handbook No. 48, are given here as a guide. It must be recognized these procedures are general and any specific emergency would certainly involve additional procedures not specifically covered in this outline. The Emergency Procedures Report (copy located at the end of this section) is to be completed as a part of the Emergency Procedures.

1. Spills involving no radiation hazard to personnel:
   a. Notify all personnel in the area at once.
   b. Permit only a minimum number of personnel in the vicinity of the spill.
   c. Confine the spill immediately.
   d. Notify the Radiation Safety Officer.
   e. Decontaminate.
   f. Monitor all personnel involved in the spill and cleaning.
   g. Permit no person to resume work in the area until it has been surveyed and approved by one of the approved individual users specified on the N.R.C. license.

2. Spills involving radiation hazard to personnel:
   a. Notify all personnel not involved in the spill to vacate the area at once.
   b. If the spill is liquid and the hands are protected, right the container.
   c. If the spill is on the skin, flush thoroughly.
   d. If the spill is on the clothing, discard outer or protective clothing at once.
   e. Switch off all fans. Vacate the room. Evacuate the area.
   f. Notify the Radiation Safety Officer as soon as possible.
   g. Take immediate steps to decontaminate personnel involved.
   h. Decontaminate the area.
   i. Permit no person to resume work in the area until a survey is made and approval of the Radiation Safety Officer is secured.
   j. Prepare a complete history of the accident and give details in the Emergency Procedures Report.

3. Injuries to personnel involving radiation hazard:
   a. Wash minor wounds immediately under running water while spreading the edges of the gash.
   b. Call a physician, preferably one who is qualified to treat radiation injuries.
   c. Permit no person involved in a radiation injury to return to work without the approval of the attending physician.
   d. Report all radiation accidents (wounds, over-exposure, ingestion, inhalation) to your supervisor.
   e. Prepare a complete history of the accident and give the details in the Emergency Procedures Report.

4. Fire and other major emergencies:
   a. Notify all personnel in the area at once.
   b. Attempt to put out all fires if radiation hazard is not immediately present.
   c. Notify the Fire Department.
   d. Notify the Radiological Safety Officer.
   e. Govern the fire fighting or other emergency activities by the restrictions of the Radiological Safety Officer.
   f. Following the emergency, monitor the area and determine the emergency devices necessary for a safe decontamination.
   g. Decontaminate.
   h. Permit no person to resume work without approval of the Radiological Safety Officer.
   i. Monitor all persons involved in combating emergency.
   j. Prepare a complete history of the accident and give the details in the Emergency Procedures Report.

L. Monitoring Techniques for Personnel

1. Check hands (finger tips), shoes, (soles and heels), face (nostrils) first.

2. Remove any contaminated clothing to a covered bin and continue monitoring.

3. ALWAYS check hands before eating, drinking, or smoking. Cleanse carefully of contamination (scrub with soap and water), and check again.

4. Allow adequate response time when using low-level detection equipment.

M. Transportation and Disposition of Radioactive Waste

1. Transportation of Radioactive Material
   a. Radioactive materials being transported must meet the same requirements as packaging of materials.
   b. When transporting radioactive materials in a passenger automobile, the materials should be carried in the trunk compartment at the furthest point possible away from the passengers or driver.
   c. When transporting radioactive materials in a truck, the materials should be carried in a closed and locked compartment at the furthest point possible away from the passengers or driver.
   d. Any vehicles transporting radioactive materials should be posted with suitable signs, if container readings or labeling require them.
   e. Radioactive materials should be packed in such a manner so that there is no danger of spilling or loss. Transportation containers must be blocked in their normal, upright position.
   f. In the event of an accident while transporting radioactive materials, every effort should be made to minimize the exposure of any persons. This could include any action such as roping off the area and notifying investigation officers. The Radiation Safety Officer should be notified immediately in order that the State Agency may be contacted if necessary.

2. Storage of Radioactive Materials
   a. Radioactive materials shall be stored in a suitable shielded container and will be covered at all times with suitable lids to prevent unnecessary exposure. Only authorized personnel shall have access to the storage facility. Suitable markings will be placed at the location.
   b. An additional storage facility of suitable construction will be provided for the storage of empty containers which have contained radioactive rags, clothing, etc. This storage facility shall remain locked at all times. Suitable markings will be placed at the location.

3. Records and Reports
   a. Maintain records showing the radiation exposures of all individuals for whom personnel monitoring is required. These records will be preserved until a date five years after termination.
   b. Each Licensee shall report by telephone and telegraph to the Federal or State Agency, the theft or loss of any source of radiation immediately upon knowledge of it.
   c. Each Licensee shall notify the Federal or State Agency upon an incident causing an individual to receive radiation in excess of the permissible limit.
   d. At the conclusion of the operation, a field study report will be presented to the customer.

4. Waste Disposal
   a. Disposal by release into sanitary sewage systems - no licensee shall discharge radioactive material into a sanitary sewage system, unless, it is readily soluble in water and does not exceed the MPC as specified in 10 CFR or applicable State regulations.
   b. Disposal by burial - no licensee shall dispose of radioactive material by burial without a permit obtained from the Federal or State authorities, or as permitted by license.
   c. Disposal by incineration - no licensee shall dispose of radioactive material by means of incineration.
   d. If it becomes necessary to dispose of any radioactive material, contact the Radiation Safety Officer, for proper steps to be taken.

5. Markings
   a. Symbols prescribed by this section shall use the conventional radiation caution colors (magenta or purple on yellow background). The symbol is the conventional three-bladed design.
   b. Use of signs - a sign or signs bearing the radiation symbol (CAUTION - RADIOACTIVE MATERIALS) shall be used in the following instances:
      (1) Radiation areas
      (2) Rooms or areas where radioactive materials are stored in quantities exceeding those specified in 10 CFR or applicable State regulations.
      (3) Containers in which radioactive material is stored.
      (4) Vehicles transporting radioactive material.
      This sign, a 14-3/4" diamond (background, safety yellow; letters, black with white top), must be clearly posted on four sides of the vehicle.

(5) Package labels:

White I	-	Surface reading no greater than 0.5 mR.
Yellow II	-	Surface reading no greater than 50.0 mR.
Yellow III	-	Surface reading no greater than 200.0 mR.

These labels must be prominently posted on opposite sides of any container shipped. They bear a description of the isotope contained in the package, the quantity and a transport index, which is the highest radiation level measure at a distance of one yard from the highest reading side of the package.

(6) Shippers Certification
This documentation will accompany the shipment and is to contain the following required information:
   a. Isotope Identification.
   b. Solid, liquid or gas.
   c. Group number.
   d. Label type (White I, Yellow II, Yellow III).
   e. Transport Index (reading at 3 feet).
   f. DOT container classification type.

Note: Other, additional, markings are prescribed in numerous regulations regarding the transportation of hazardous materials.

V. SAFETY PROCEDURES FOR HANDLING RADIOACTIVE TRACERS

A. Introduction - In order to give proper safety consideration to the various radioactive materials used in tracer surveys, the following information should be understood by all field users. The relatively low activity levels of the tracer units allow some latitude in handling techniques such that moderate safety precautions are sufficient. However, the ALARA concept and policy will be followed at all times.

The major safety problem is the prevention of accumulation of radioactive material in the body. The activities typically used are from 100 to 10,000 times the tolerable limit for internal accumulation. The degree of this particular hazard depends on the biological activity of the isotope, its half-life and the nature of the tracer preparation.

B. Handling Procedures - The large variety of tracer preparations used, or available for us, is such that no fixed procedures can be specified for each tracer unit. In general though, the majority of tracers may be handled for a few minutes without the use of extension tools. Protective clothing and equipment must always be worn.

Chart 1 gives the allowable handling time in minutes per week for various amounts of Iodine (I^{131}), Iridium (Ir^{192}), Scandium (Sc^{46}). This chart is based on actual measurements made by General Nuclear and a maximum radiation exposure of 4.69 rem per quarterly tolerance (18.75 rem) for the hands, forearms, feet and ankles as was specified in the pertinent Federal and/or Agreement State regulations. *New regulations, effective January 1, 1994, specify annual limits, and different exposure doses (see page 10 of this manual and Glossary)*. We must stay within the handling times as indicated on the chart in order that we may continue to handle the unshielded tracer units without the benefit of hand-type monitoring devices such as wrist film badges, finger dosimeters, etc. or remote handling devices. However, the use of the normal safety equipment such as survey meters, rubber gloves, etc. and the regular film badge is still required. Historically, actual exposures have remained well below these limits. Proper technique will insure that future exposures also remain very low.

The allowable handling time is determined as the maximum time in minutes per week that a person can work with his hands (rubber gloved) in direct contact with unshielded tracer units. The allowable handling time as indicated on Chart 1 is not additive - that is, you cannot, for example work for 18 minutes with 10 millicuries of Ir^{192} and 42 minutes with an equal amount of I^{131} in one week. If several hand exposures to both types of tracer materials are received during one week, the exposures must be rationed.

Example: If in one calendar week a person directly handles 20 millicuries of I^{131} for 3 minutes, 10 millicuries of Ir^{192} for 3 minutes, and 15 millicuries of I^{131} for 4 minutes, these exposures are totaled as follows: From the chart the allowable handling time for 20 millicuries of I^{131} is 21 minutes. Hence the exposure to the hands for 20 millicuries of I^{131} is 3/21, or 0.143 of the weekly allowable handling time. Similarly, the exposure for the 10 millicuries of Ir^{192} is 3/18, or 0.167; and that for the 15 millicuries of I^{131} is 4/28, or 0.143. Adding these three fractions, 0.143 + 0.165 + 0.143 = 0.453, or a little less than half the total allowable handling time for that particular calendar week.

Charts 2 and 3 indicate the radiation levels that are present for various amounts of the tracer materials at one and three feet from the unshielded tracer units.

Please remember that tolerances are not meant for working levels but as maximum safe levels only, and that the objective should be to obtain a minimum exposure during tracer operations. This can be accomplished by working as rapidly, yet carefully, as possible with the tracer units and also by distributing the actual direct handling of the unshielded materials among as many qualified people as possible.

C. Contamination Survey Techniques

1. Surveying of Area and Equipment

The ideal tracer operation would have no spills and leave no residue of tracer material in any of the equipment through which the tracer was injected. In practice such an ideal may not be realized, and a survey of the area is necessary so that the proper procedures may be followed to assure that no remaining contaminant can cause harm to company personnel, the customer's personnel, or the general public.

A survey meter must be used to survey the entire area where a tracer operation has been done, and the equipment through which the tracer operation was conducted, to be sure that no concentration remains that may cause harm, either by external radiation or by possible contamination of food or water supplies.

Contamination of the probe or meter must be avoided completely. If any contact survey is made, the probe is to be protected with a sheet of paper or plastic covering between the object and probe. A contaminated probe can render the survey meter useless for low level measurements. Spills should be cleaned up and properly disposed of. The area of the spill should then be surveyed with the probe approximately one inch above the surface.

2. Surveying of Individuals

The greatest care in survey measurement is taken on items of personal equipment such as shoes, gloves, clothing and handling tools, as well as exposed portions of the body of personnel working with radioactive materials. This is because of the much greater probability of ingestion from such items.

The survey meter should be used to read the radiation level of clothing worn by the individual performing the tracer operations or any other clothes suspected of contamination. This should be done immediately following the tracer operation. If any indication of radioactive contamination is found on items of clothing, equipment, etc., or on the person or personnel involved in the operation, every effort should be made to remove the activity. (See paragraph below for decontamination procedure.)

D. Decontamination Procedure

The normal radioactive tracer preparations are significantly below the dangerous levels for external radiation hazards. The major hazard involved with these tracer preparations is the factor of ingestion, and prolonged exposure. The ingestion tolerance is from one part per thousand to one part per ten thousand of the typical activities used. Thus, great care must be exercised by company personnel to avoid contamination of hands, clothing and other personal items. Accidental spills of radioactive materials are to be cleaned up, dispersed, or disposed of safely.

Decontamination shall, in general, be accomplished by rinsing and flushing water or flush fluid through the equipment, or washing and scrubbing of contaminated items of clothing or portions of the individual's body. A detergent may be added to the water to aid this process. Portions of the equipment which cannot be decontaminated by this method shall be disassembled and hand scrubbed with water and detergent. A 15% hydrochloric acid solution may be used to remove contamination from the surface of non-porous materials. Other chemicals may be used for decontamination but their use should be limited if they are classified as hazardous in nature.

Articles of clothing can normally be decontaminated by spot washing and scrubbing with water containing a strong detergent. This also applies to the exposed individual's body. Take care not to spread contamination. All fluids used for decontamination will be treated as radioactive waste. If efforts to decontaminate items of clothing on the job are unsuccessful, the clothing should be removed immediately to be decontaminated after returning to the home station nearest the job location. Contaminated articles of clothing, rags, etc. should never be laundered. Decontamination is restricted to the job site or the company base. If the contamination cannot be removed economically, the clothing shall be discarded and treated as radioactive waste, and stored for decay.

1. Rubber gloves shall be worn during decontamination procedures involving personal contact with the equipment.

2. Food, cigarettes, etc., shall be kept outside the clean-up area. Quantities of radioactive material which present no hazard outside the body can be very dangerous if the same amount is introduced internally.

3. The wash water shall be treated as radioactive waste and shall not be discharged into sanitary sewage systems without authorization from the RSO. To discharge waste into sanitary sewage system, the activity would have to be diluted during the disposal to a level not to exceed the regulations. This procedure requires documentation of discharge.

   No wash water shall be discharged into a septic tank. In the event of accidental discharge, the fluid in the septic tank shall be surveyed, and if any activity above background is noted, the tank shall be posted with radiation warning signs alerting everyone concerned of the possible hazard.

   If standard decontamination efforts are unsuccessful, the procedure to be followed shall depend on the value and ownership of the items involved, the degree of contamination and the half-life of the contamination activity. Every effort shall be made to thoroughly decontaminate rented or borrowed equipment. If all efforts to decontaminate items of equipment, clothing, etc., have failed to render the radioactive contamination to background and the measurable activity is apparently "fixed", the user in charge has three alternatives:

   a) If the "fixed" contamination measures less than 0.2 mR/hr at one centimeter, then the item of equipment, article of clothing, etc., can be returned to normal use. Items removed from use for decontamination shall be identified and the results of decontaminated shall be documented. A report will be given to the owner of rented or borrowed equipment.

   b) If the "fixed" contamination measures more than 0.2 mR/hr at one centimeter, the item or items in question shall be treated as radioactive waste and disposed of accordingly.

c) If the items containing the "fixed" contamination (measures more than 0.2 mR/hr at one centimeter) are such that they are continually used in tracer operations, e.g. parts of a dump bailer, tracer injector, etc., use of the item may be continued if it is properly labeled and treated as a radioactive source and if the item measures less than 2 mR/hr at three inches from the surface.

More persistent activity levels remaining on injection apparatus, customer's equipment, etc., can be steam cleaned or chemically treated for contamination. Steam cleaning will generate a large volume of wash water and shall not be done without authorization from the RSO.

The user in charge shall be responsible for all contaminated equipment. That is, for any equipment, waste, area or wash water that falls within the above alternative situations. The user in charge shall personally supervise its safe disposition either by staying on the job until the contamination is removed or transporting the equipment to the base where it may be stored, awaiting further decontamination.

VI. GLOSSARY

A. Terminology

Radioactivity:

The property possessed by some elements (e.g.: uranium) of spontaneously emitting alpha, beta or gamma rays by disintegration of the nuclei of the atoms. An element is said to be radioactive if it can spontaneously decay or be transformed into another element. This transformation is always accompanied by emission of nuclear radiation.

Isotope:

Species of atoms of a chemical element with the same number of protons, but differing in the number of neutrons in their respective nuclei, resulting in the same atomic number, but different atomic masses and nuclear properties. Some isotopes are unstable, releasing energy in the form of radioactivity; they are called radioisotopes.

Alpha particle:

A positively charged nuclear particle identical with the nucleus of a helium atom. It consists of two protons and two neutrons and is ejected at high speed from the nucleus of an atom in certain radioactive transformations.

Beta particle:

An electron or positron ejected from the nucleus of an atom during radioactive decay.

Gamma ray:

A photon emitted spontaneously from the nucleus of an atom of a radioactive substance. It is not a particle but a form of electromagnetic radiation, similar to light.

X-ray:

A photon emanating from outside the nucleus of an atom. It is not a particle but a form of very short wave length electromagnetic radiation, similar to gamma rays but originating outside the nucleus.

Bremsstrahlung:

The secondary photon radiation (X-ray) produced by the deceleration of charged particles (especially beta particles) as they pass through matter (from German for "braking radiation").

Neutron:

A neutron is an elementary nuclear particle with a mass slightly greater than a proton and a net charge of zero.

Activity [Curie]:

The activity of a radioactive substance is often designated by the Curie [Ci]. The Curie is not a measure of dose; it merely states the amount of a radioactive substance disintegrating per unit time. The Curie is a unit of measurement defined as the activity of a radioactive substance disintegrating at a rate of 3.7×10^{10} disintegrations per second.

Millicurie:	1/1,000 Ci	[mCi]
Microcurie:	1/1,000,000 Ci	[μCi]
Nanocurie:	1/1,000,000,000 Ci [ηCi]	
Picocurie:	1/1,000,000,000,000 Ci	[ρCi]

Exposure [Roentgen]:

As a beam of photons passes through air, the interactions which take place produce electrons, which then lose energy by creating ion pairs. The exposure is measured by collecting and measuring these pairs. Thus, the exposure concept is based on the ability of photons to produce ionization. The special unit of exposure is the Roentgen [R]:

$$1 \text{ R} = 2.58 \times 10^{-4} \text{ Coulomb / kilogram of air}$$

Milliroentgen: 1/1000 R [mR]

(This unit is numerically equal to the older definition for Roentgen: 1 R = 1 esu/cc of air; an exposure to X or gamma radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air, ions carrying one electrostatic unit or quantity of electricity of either sign.)

Absorbed dose [rad]:

The rad is the unit of absorbed dose (D) measuring the energy imparted by ionizing radiation to matter.

1 rad = .01 Joule/kilogram (or: 100 ergs/gm)

Dose equivalent [rem]:

The dose equivalent concept allows the scaling up of the absorbed dose in order to better compare the effect of different types of radiation on human systems. Dose equivalent (DE) is expressed in rem (roentgen equivalent man) and is defined as the product of absorbed dose (D) in rads and other necessary modifying factors.

In normal protection work the product of absorbed dose and quality factor (QF) expresses the irradiation in terms of a common scale for all ionizing radiations.

$$DE = D \times QF \ldots \qquad [rem]$$

Examples of QF are:

Type of Radiation	Quality Factor(QF)
X-ray, gamma ray, beta particles	1
Alpha particles	10
Heavy recoil atoms	20
Neutrons	2 to 10.5

In regard to protection purposes the term QF replaces the former term RBE (relative biological effectiveness); in order to talk about RBE one must define exposure conditions as well as the effect studied.

Much effort has been directed toward the problem of calculating the dose which a person receives as a result of internally deposited radionuclides. Among the many factors of main concern that enter into such a calculation are: the shape of the organ, the type of radiation and the distribution of the deposit. The distribution factor (DF) is used to correct for non-uniform distribution in the case of internally deposited radionuclides. Thus, the dose equivalent becomes:

$$DE = D \times QF \times DF \ldots \qquad [rem]$$

Exposure rate [R/hr]:

The exposure (X) is defined in terms of ionization produced in a volume of air. The exposure rate is given by the quotient of exposure and time (t).

Exposure rate = X / t [R/hr]

The special unit of exposure rate is Roentgen per hour, or milliroentgens:

Milliroentgen per hour: 1/1000 R/hr [mR/hr]

A simple formula for use in Health Physics applications to estimate the exposure rate at a distance of one meter from a known isotropic point source of activity C [Ci] and energy E [MeV] for an energy range form .2 MeV to 2 Mev in air is:

Exposure rate = 0.53 x C x E [R/hr]

Half-life:

The physical or radioactive half-life is the time required for the activity of a given isotope to decay to one-half of its initial value. In evaluating the effects of radioactive substances deposited in the human system we need to address two additional half-lives:

1. The biological half-life: It is the time required for the body to eliminate one-half of the amount of a radioactive substance internally deposited by excretion, exhalation and perspiration.

2. The effective half-life: It is defined as the time required for the radioactivity from a given amount of radioactive substance deposited in the tissues or organs to diminish by 50 % as a result of the combined action of radioactive decay and loss of the material by biological elimination. The effective half-life is usually experimentally determined.

Half-value layer:

The half-value layer is the thickness of a substance which reduces the intensity of a beam of radiation to one-half of its initial value. The half-value layer is a function of the energy of the gamma and the composition of the shield or absorber. Examples:

Radioactive Material		Lead	Steel	Concrete
Co^{60}		0.49"	0.87"	5.0"
Cs^{137}		0.25"	0.68"	2.1"
Ir^{192}	0.19"	0.50"	1.9"	
I^{131}		0.14"	0.37"	1.4"

The inverse square law:

The radiation field decreases with distance from the source. When considering a point source in air, the decrease will follow the inverse square law, which states that the amount of radiation at a given distance from a source is inversely proportional to the square of the distance.

$I/i = d^2/D^2$ or $I \times D^2 = i \times d^2$

(Where I = intensity at a distance (D) from a point source, and i = intensity at a distance (d) from the same source).

Example: If the exposure rate at 1 meter equals 100 mR/hr then the exposure rate at 2 meters equals 25 mR/hr.

Examples of exposure rates versus distance for 100 mCi sources of Iodine and Iridium:

Radioactive Material	mR/hr @ 3'	mR/hr @ 6'	mR/hr @ 9'
Ir^{192}	61	15.25	6.8
I^{131}	25	6.25	2.8

ALARA concept:

The philosophy inherent in any program of radiation safety is to reduce exposure, whether internal or external, to a minimum:

"As Low As is Reasonably Achievable".

Whenever it is impossible or impractical to remove a source of radiation, other means must be considered for purposes of personnel protection. Three factors which determine the total exposure one receives in a given radiation field are (memory aid: Time-Distance-Shielding):

1. Time of exposure.
2. Distance from source.
3. Amount of shielding present.

The following is an excerpt from the Federal Register, Title 10, Volume 1, January 1, 2002, Page 309, 10CFR20.1003 (definitions):

ALARA (acronym for ``as low as is reasonably achievable'') means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

Page 318, Subpart B--Radiation Protection Programs, Sec. 20.1101 Radiation protection programs 10CFR20.1101 (b)

The licensee shall use, to the extent practical, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA).

Shielding:

Shielding is a method of radiation protection. A shield is a body of material positioned to prevent or reduce the passage of radiation. The effectiveness of a shield is determined by the interaction between the incident radiation and the absorbing medium.

Alpha radiation:

Alpha particles can be stopped by very thin absorbing materials, e.g.: a few sheets of paper, or, 1/64th inch of aluminum foil. Since alpha particles travel only short distances in air, and alpha particles up to 7.5 MeV are absorbed by the outer layer of skin (dead tissue), alpha radiation is not considered an external exposure problem.

Beta radiation:

Though Beta particles have a greater penetration in any absorber than alpha particles, they can still be stopped by thin absorbing materials, e.g.: 1 inch of wood, or 1/4 inch of Lucite. However, bremsstrahlung must be considered in shielding beta radiation: the higher the atomic number (Z) of the absorber, the greater the percentage of bremsstrahlung. Combination shields are effective, e.g.: for transport containers; a low-Z absorber can be used to stop the betas, followed by a high-Z absorber to attenuate the bremsstrahlung.

X and gamma radiation:

Photons are much more penetrating than alpha and beta particles. X and gamma radiation is never completely absorbed; however, we can choose a shield composition and thickness which will reduce the intensity to non-hazardous levels (see also: half-value layer). Generally, high density materials are best suited for gamma shielding.

Radiation detection:

Radiation cannot be detected with the unaided senses. An instrument must be used to identify presence, type or intensity of radiation. All instruments consist of a detector and a measuring apparatus (some substance that responds to the radiation and a system to measure the extent of the response). Some detection systems use the ionization produced in them, and other systems depend upon excitation. Chemical and photographic detection principles are also used.

Atom:

Smallest particle of an element which is capable of entering into a chemical reaction.

Contamination:

Deposition of radioactive material in any place where it is not desired, particularly where its presence may be harmful.

Curie:

Units of measurement (see Activity). One curie is that quantity of a radioactive nuclide disintegrating at the rate of 3.700×10^{10} atoms per second.

microcurie	=	$1/10^6$ of curie or 3.7×10^4 disintegrations / second.
millicurie	=	$1/10^3$ of curie or 3.7×10^7 disintegrations / second.
picocurie	=	$1/10^6$ of microcurie or 3.7×10^{-2} disintegrations / second, or 2.22 d/minute.

Decontamination factor:

The ratio of the amount of undesired radioactive material initially present to the amount remaining after suitable processing steps have been completed.

Film Badge:

A pack of photographic film which measures radiation exposure for personnel monitoring. The badge may contain two or three films of different sensitivity and filters to shield parts of the film badge from certain types of radiation.

Health Physics:

A science and profession devoted to the protection of man and his environment from unnecessary radiation exposure.

Ion:

Atomic particle, atom or chemical radical bearing an electrical charge, either positive or negative.

Ionization:

The process by which a neutral atom or molecule acquires a positive or negative charge.

Ionization Radiation:

Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

Radiograph:

Record of radiation from radioactive material in an object, made by placing the object in close proximity to a photographic emulsion.

Roentgen (R):

The basic unit of exposure to X or gamma radiation. The special unit of exposure. One R = 2.58 x 10^{-4} coulombs/Kg of air. One milliroentgen (mR) is equivalent to 1/1000 of one Roentgen.

X-Ray:

Penetrating electromagnetic radiation whose wave lengths are shorter than those of visible light. They are usually produced by bombarding a target (metallic) with fast electrons in a high vacuum. In nuclear reactions, it is customary to refer to protons originating in the nucleus as gamma-rays and those originating in the extranuclear parts of the atom as X-rays. They are sometimes referred to as Roentgen rays after Wilhelm Conrad Roentgen, the discoverer. The only difference between X and gamma radiation is the source (origin) of the radiation.

B. Biological

Absorbed Dose:

The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the RAD. One RAD = 100 ergs per gram.

Bioassay:

The determination of kinds, quantities, or concentrations, and, in some cases, the locations of radioactive material in the human body, whether by direct measurements, in vivo counting, or by analysis and evaluation of materials excreted or removed from the human body.

Bone Seeker:

Any compound or ion which migrates in the body, preferable to the bone.

Carcinogenic:

Capable of producing cancer.

Committed Dose Equivalent ($H_{T,50}$):

The dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

Committed Effective Dose Equivalent ($H_{E,50}$):

The sum of the products of weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to each of these organs or tissues.

Cumulative Dose:

Total dose resulting from repeated exposure to radiation.

Deep Dose Equivalent:

The dose equivalent at a tissue depth of 1 centimeter (applies to external whole body exposure).

Dosimeter:

Instrument to detect and measure accumulated radiation exposure.

Dose:

The absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, total organ dose equivalent, or total effective dose equivalent.

Dose Equivalent (H_T):

The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest.

Dose Limits:

The permissible upper bounds of radiation doses.

Effective Dose Equivalent (H_E):

The sum of the products of the dose equivalent to each organ or tissue (H_T) and the weighting factor (W_T) applicable to each of the body organs or tissues that are irradiated.

External Dose:

That portion of the dose equivalent received from any source of radiation outside the body.

External Radiation:

Radiation originating from a radiation source outside the body and probably the most frequently encountered hazard.

Extremity:

Hand, elbow, arm below the elbow, foot, knee, and leg below the knee.

Eye Dose Equivalent:

The external dose equivalent to the lens of the eye at a tissue depth of 0.3 centimeter.

Genetic Effects of Radiation:

Inheritable change chiefly mutation, produced by the absorption of ionizing radiation. On the basis of present knowledge, these effects are purely additive, there is no recovery.

Internal Dose:

That portion of the dose equivalent received from radioactive material taken into the body.

Internal Radiation:

Material taken into the body through the body openings, through abrasions or cuts and by skin absorption. There are four common ways in which it is possible to get radioactive materials into the body:

1. Breathing
2. Swallowing
3. Through breaks in the skin
4. By absorption through the skin

Maximum Permissible Concentration (MPC)

The highest currently acceptable concentration of radioactive substances (usually expressed as microcurie per cubic centimeter, $\mu Ci/cm^3$) in air, water of food to which an individual may be exposed throughout a stated period of time, without expectation of injury.

Maximum Permissible Dose (MPD)

That dose of ionizing radiation that a person may receive in his life time without producing any appreciable bodily injury. The presently accepted MPD is:

$$MPD = (N - 18) \times 5 \qquad \text{(rem)}$$

where N is the individual's age (greater than 18).

Note: Effective January 1, 1994, this definition has been superseded by new regulations. It has been retained for historical completeness. See page 10, and other definitions this section.

Maximum Permissible Dose Equivalent:

The greatest dose equivalent that a person or specific part thereof shall be allowed to receive in a given period of time.

Occupational Dose:

The dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to sources of radiation.

Permissible Dose:

The dose of radiation which may be received by an individual within a specific time period with expectation of no significantly harmful results.

RAD:

The unit of absorbed dose equal to 0.01 J/kg.

Radiation Sickness:

A self-limited syndrome characterized by nausea, vomiting, diarrhea and physic depression following exposure to appreciable doses of ionizing radiation. It usually appears within a few hours after irradiation and may subside within a day.

Shallow Dose Equivalent (H_s):

The dose equivalent at a tissue depth of 0.007 centimeter, averaged over an area of 1 square centimeter (applies to external exposure of the skin or an extremity).

C. Classification Of Radiation Doses

Mild dose:

A small dose of radiation which produces no detectable clinical effects on the body (25-50 rem).

Moderate Dose:

Acute exposure with doses ranging from 50 to 200 rem. Injury may vary from slight to serious. Recovery from moderate doses of radiation is likely unless complications arise related to poor health or injuries or if infection occurs.

Median Lethal Dose (MLD):

When acute exposure results in a dosage from 200 to 600 rem there is a possibility of up to 50% mortality. Injury and disability are certain at higher exposure.

Acute Effect:

Those effects of radiation which appear within approximately one month, which includes the immediate (0 - 48 hours) and the delayed (1 - 5 weeks) effect.

Chronic Effects:

Long term effects of radiation which result in persistent changes (eg., radiation dermatitis) and vascular or atrophic changes (appearing after one year -- eg., tumor indication, cataract formation).

VII. CHARTS AND REPORTS

A. Chart 1 - Hand Exposure From Radioactive Tracers

B. Chart 2 - Radiation Levels At One Foot From Unshielded Radioactive Tracers

C. Chart 3 - Radiation Levels At Three Feet From Unshielded Radioactive Tracers

D. Emergency Procedure Report