Atomic Energy of Canada Limited

ONE-DAY INTRODUCTION TO RADIATION PROTECTION PRINCIPLES

by

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Chalk River Nuclear Laboratories
Chalk River, Ontario

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This report is based on Report AECL-2656

by J.H. Fenn, W.R. Bush and L.C. Watson

as revised in July, 1970

ABSTRACT

The fundamentals of radiation hazards and their control are outlined. This one-day course is presented to all classes of radiation workers at CRNL, usually during their first month of employment.

The purposes of the course are to outline the fundamentals of radiation hazards control, to describe methods that enable employees to work safely with radiation, and to acquaint employees with the CRNL radiation and industrial safety organization.

Radiation and Industrial Safety Branch
Chalk River Nuclear Laboratories
Atomic Energy of Canada Limited
Chalk River, Ontario

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Initiation d'un jour aux principes de la radioprotection

par

J.H. Fenn, J.M. White et L.C. Watson

Ce rapport est fondé sur le rapport AECL-2656 de J.H. Fenn, W.R. Bush et L.C. Watson, tel qu'il a été révisé en juillet 1970.

Résumé

Les notions fondamentales du danger des radiations et de leur contrôle sont passées en revue. Ce cours d'une journée est présenté à toutes les catégories de travailleurs susceptibles d'être exposés aux radiations, à Chalk River, généralement durant leur premier mois d'emploi.

Le but du cours est de donner un aperçu des aspects fondamentaux de la radioprotection, de décrire les méthodes permettant aux employés de travailler en toute sécurité près des radiations et de familiariser le personnel avec l'organisation de la sécurité industrielle et de la radioprotection à Chalk River.

L'Energie Atomique du Canada, Limitée
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1. PURPOSE

The fundamentals of radiation hazards and their control are presented to employees of the Chalk River Nuclear Laboratories (CRNL), usually during their first month of employment. The course is intended for all classes of workers who are expected to work continuously or occasionally in areas where radiation or contamination could be encountered. The course is presented in about six hours. Similar courses have been given, by J.H. Fenn, since March of 1957.

The purposes of this course are:

- to outline the fundamentals of radiation hazards control,
- to describe methods that enable employees to work safely with radiation,
- to demonstrate some of the safe techniques used when handling radioactive materials,
- to acquaint employees with the CRNL radiation and industrial safety organization.

2. FUNDAMENTALS

2.1 What is Radiation?

The type of radiation discussed in this course is called ionizing radiation, and is associated with radioactive materials, X-ray machines and accelerators. Ionizing radiation differs from the more familiar types of radiation, light and heat, in that we cannot see it, feel it, or detect it with any of our senses. However, we can detect it with radiation measuring instruments.

Ionizing radiation consists of streams of fast flying particles or energy waves, which are emitted by atoms. Atoms are incredibly small units of matter. Although all substances are made up of atoms, not all atoms emit ionizing radiation. Some atoms have too much energy, which makes them unstable. Such unstable atoms are radioactive, and are called radioisotopes. They change spontaneously into more stable isotopes by the process of radioactive decay. In so doing, they give off some of their excess energy in the form of ionizing radiation.

Radioactive decay proceeds at a specific, unalterable rate for each type of radioisocope. The time required for a radioisotope to decay to half of its initial strength, or to lose half its activity, is called its half-life.

2.1.1 Types of Radiation

The four types of radiation most frequently encountered at CRNL are:

2.1.2 Alpha Particles Symbol: α

Alpha particles are invisible particles which travel only about 1.5 inches in air or 0.002 inches in water. They are encountered at CRNL mainly as contamination in and around hot cells and in various laboratories where alpha-emitting isotopes such as plutonium (Pu), uranium (U) or thorium (Th) are handled. Beta and gamma radiation will usually be present in these locations too.

2.1.3 Beta Particles Symbol: β

Beta particles are invisible particles (electrons) which are about one hundred times more penetrating than alpha particles. High energy beta particles travel up to several yards in air, or up to one inch in water; however, the maximum range of the beta particles most common at CRNL is about 10 feet in air or 1/8 inch in water.

Beta particles are encountered at CRNL mainly in areas that are contaminated with fission products from irradiated fuel, such as fuel storage bays, hot cells and various laboratories. Intense beta fields also arise from other materials that have been in a reactor, and from various radioisotopes that may be found in laboratories.

Beta radiation is usually accompanied by gamma radiation. In some cases the hazard will be greater from the beta particles, and in others, from the gamma rays.

2.1.4 Gamma Rays Symbol: γ

Gamma rays are electro-magnetic waves similar to light, but are extremely penetrating. They are identical to X-rays; however, they are emitted by radioisotopes whereas X-rays are usually produced by machines.

The distance the γ-rays can travel through a material depends on their energy, but even weak γ-rays are very penetrating. The thicknesses of material required to reduce the intensity of energetic cobalt-60 γ-rays to one-tenth are

14 inches of water, 2.2 inches of iron, or 1.3 inches of lead, for narrow γ-ray beams, or about 26 inches of water, 3.2 inches of iron, or 1.7 inches of lead for wide beams.

Gamma rays are associated with most alpha and beta sources. However, alpha and beta particles are often shielded out by the walls of containers, whereas γ-rays are not. Therefore, γ-rays are the most common type of radiation encountered at CRNL. Gamma radiation may be encountered in many areas around reactors, in fuel storage bays, in hot cells, around accelerators, and in various laboratories.

2.1.5 Neutrons Symbol: n

Neutrons do not produce ionization themselves, but they produce it indirectly, so are included here as ionizing radiation. Neutrons are invisible particles which may be encountered in the reactor and accelerator buildings. They are generated during the fissioning of uranium and plutonium in reactors, and are also produced by various reactions in accelerators. Neutrons are released from beryllium upon irradiation with alpha particles. Portable neutron sources may be found in various laboratories. These are made up of mixtures of beryllium (Be) with one of the alpha emitters: radium (Ra), polonium (Po), actinium (Ac) or plutonium (Pu).

Neutrons travel very fast when they are generated, and are slowed down as they travel through various materials. Slow or fast neutrons may be absorbed (captured) by the atoms of the material through which they are travelling. Neutron capture is usually accompanied by the release of gamma rays.

The effectiveness of various materials in slowing and capturing neutrons varies widely from one material to another, and even from one isotope to another in the same substance. It also depends strongly on the neutron energy. Therefore, it is difficult to specify the range of neutrons in simple terms. When fast neutrons travel through ordinary water, 90% of them are slowed and captured after travelling about one foot.

2.2 Why Radiation is a Health Hazard

The body is made up of organs (e.g. skin, eyes, intestines, blood-producing organs, reproductive organs), which are comprised of tissues (e.g. muscle, nerve, bone), which are comprised of cells. Radiation initiates a series of reactions that may affect the metabolism of cells, thereby resulting in damage to tissues and organs. Extremely high exposures can result in ulcer-like skin burns, in cloudiness of the eye (cataract), or in dangerous damage to the blood-producing organs or intestines. However, if radiation exposures are kept within the permissible limits (section 5.2), the damage is slight and is considered acceptable.

Other types of injury may develop years after a radiation exposure is received. The most notable of these is leukemia. The risk of leukemia from the radiation exposures permitted at CRNL is extremely small.

Another type of injury, called genetic damage, has no apparent effect on exposed persons, but is inheritable and may result in the children or later descendants of exposed persons being born with physical or mental defects. Genetic damage is permanent and is cumulative. That is, the greater the exposure accumulated by a person all through his life until the conception of children, the greater the probability of genetic damage. The radiation dose limits observed at CRNL are low enough that the amount of genetic damage we pass on to our descendants should be minimal.

3. EXTERNAL EXPOSURE

External exposure arises from a radiation source that is located outside the body.

3.1 Whole Body Irradiation

Gamma rays, X-rays and neutrons are very penetrating and can pass right through the body. As they pass through the body they irradiate everything, including skin, blood, bones and internal organs.

3.2 Skin and Eye Irradiation

Beta particles can penetrate the skin and the outer surface of the eyes, but not much further. Therefore, only the skin and eyes are irradiated when the body is exposed to β particles.

Most alpha particles cannot penetrate the skin, therefore substances that emit alpha particles are usually harmless as long as they remain outside the body.

3.3 Beams and Solid Sources

External exposures at CRNL most commonly arise from sources such as:

- open experimental or fuel holes in reactors
- accelerator beams and targets
- anything that is removed from a reactor
- fuel and other irradiated materials in fuel storage bays or hot cells (caves)
- equipment and wastes from storage bays and hot cells
- contamination around storage bays, hot cells, and reactors
- piping systems in reactor and chemical plant buildings
- radioisotopes in various laboratories

The radiation hazards associated with reactors and accelerators are generally greater when these devices are operating, but dangerous levels of radiation can also be encountered when they are shut down.

3.4 Radioactive Gases

External exposures may also be received from radioactive gases that occasionally escape from reactors or reactor fuels. The most common of such gases are fission-product kryptons and xenons, and argon-41. Only traces of these gases are absorbed into the body, and since they are chemically inert, they are not retained. Therefore, they pose mainly an external radiation hazard. However, radionuclides such as radioiodine could be present in the air at the same time as these gases. Therefore respirators are generally worn to prevent inhalation of these radioisotopes which are absorbed into the body when workers are exposed to high concentrations of radioactive gases (See Section 4).

3.4.1 Inert Fission-Product Gases

These are radioisotopes of krypton and xenon. They may be evolved from damaged fuel after it is removed from a reactor, or they may accompany leaks of heavy water or helium from reactor systems. The particulate decay products of fission-product gas mixtures usually encountered are characterised by the 17.7-minute decay half-life of rubidium-88 (sometimes apparently lengthened because of the presence of cesium-138 with a 32.2 minute half-life).

3.4.2 Argon-41

This is produced when air is irradiated in reactors, either in rod assemblies or in various air-cooled parts of reactors. Argon-41 has a half-life of 1.8 hours. It occasionally leaks from reactor systems and produces an external hazard which, although usually mild, could be quite dangerous.

Under certain weather conditions, argon-41 descends from the main stack and blankets the entire CRNL area. (See Section 10.5.) When this happens, the concentration is too low to pose a significant hazard, but is high enough to raise the background radiation level and so interfere with radiation measurements.

3.5 Precautions Against External Exposures

Three general types of precaution are taken in order that men may work safely in areas where alpha, beta, gamma or neutron sources are present:

3.5.1 Time

The longer the time spent near a radiation source, the greater will be the exposure. Therefore, if it is necessary to work where radiation is present, the simplest way to limit the exposure is to stay as short a time as possible.

3.5.2 Distance

Exposure rate decreases rapidly with distance from a source. To reduce radiation exposures all work should be carried out as far as practicable from sources of radiation.

The intensity of gamma radiation decreases as the inverse square of the distance from a source. Doubling the distance from a gamma source decreases the dose rate to one-quarter, while tripling the distance reduces the dose rate to one-ninth, and so on. The intensity of beta radiation decreases even faster with distance, because some of the beta particles are absorbed by the air.

3.5.3 Shielding

Shielding can be used to reduce or eliminate radiation.

Alpha radiation is easily shielded by rubber gloves, paper or clothing.

Beta radiation is more difficult to shield than alpha, but may be shielded by plywood, asbestos, lucite, aluminum or other material of low atomic number.

Gamma radiation is very penetrating, and requires thick shields of dense materials such as lead, steel, or concrete. Water is often a convenient shield, but the thickness required for a desired shielding is about ten times more than if lead is used.

Neutrons are often shielded by mixtures of heavy and light materials, such as sandwich-type blocks made up of alternate layers of steel and masonite. Materials containing a high proportion of hydrogen and carbon atoms such as parawax can be used to slow fast neutrons so they can be absorbed by other materials.

4. INTERNAL EXPOSURE AND CONTAMINATION

4.1 Contamination

Contamination is uncontained radioactive material in a location where it is not wanted. It may be encountered in several forms:

- as visible or invisible dust on surfaces or in the air,
- as visible or invisible moisture on surfaces,
- as visible or invisible gas or vapour in air, or
- as visible or invisible smoke or fumes.

Radioactive contamination can be encountered at concentrations high enough to pose an extremely dangerous external radiation hazard due to its beta and gamma radiations. However, it is not hazardous at the levels usually encountered unless it enters the body. Once inside, it irradiates all or part of the body until it decays or is excreted. Such internal irradiation may continue for a long time (days or years), therefore amounts of contamination that are too small to present a significant external radiation hazard can be extremely hazardous if they can enter the body. Furthermore, contamination that emits only alpha particles or low-energy beta particles is completely harmless until taken into the body; then it can be extremely hazardous.

4.2 Entry Into the Body

4.2.1 Inhalation

Contamination may be inhaled into the lungs when we breathe air that contains radioactive dust, gas, vapour, fumes or smoke. Dangerous quantities could be inhaled even when the airborne contamination is completely invisible. The size of the dust particles which carry the contamination is usually from 0.1 microns to 10 microns in diameter. Larger particles rapidly fall out of the air and smaller particles behave like a gas.

Some inhaled substances are completely absorbed through the lungs into the body; some are carried slowly out of the lungs in mucous and then swallowed and introduced into the G.I. tract; some of the smaller sized particles are exhaled immediately after inhalation; and some remain in the lungs.

Inhalation of radioactive contamination is prevented by proper engineering controls or as a last resort by wearing respirators in contaminated areas.

4.2.2 Ingestion

Contamination may be ingested (swallowed) if articles such as pipes, cigarettes or fingers become contaminated and then touch the lips or are put in the mouth. Large amounts of contamination could be ingested if radioactive liquids were pipetted using the mouth rather than a mechanical device for suction.

Some ingested materials are absorbed completely into the body via the G.I. tract, whereas others are partially absorbed and partially eliminated in the faeces.

Ingestion is prevented by good habits such as not smoking in contaminated areas, not brushing contaminated hands across the face, and washing before eating.

4.2.3 Skin Absorption

Although the skin is an excellent barrier for most substances, some materials are absorbed through the skin into the body. The most notable example is tritium (See Section 4.5). Contamination dissolved in some organic solvents may also soak into the skin and be absorbed.

The skin can be damaged by harsh cleaning techniques to permit absorption of contamination. Radioactive material can also enter the body through skin that is damaged by cuts, scratches or scrapes.

Absorption of contamination through the skin is prevented by wearing gloves and protective clothing to keep contamination off the skin. When the skin does become contaminated, it should be washed with soap and water repeatedly. If the contamination still persists the R. & I. S. Branch should be consulted.

4.3 Fission-Product Contamination

Hundreds of different fission products are produced from uranium and plutonium in nuclear reactors. For simplicity, two of the more hazardous fission products, strontium-90 and iodine-131, are often the main ones considered. If these are controlled to safe levels, then the less hazardous fission products will also be under control when dealing with unseparated fission products.

4.3.1 Strontium-90

Strontium-90 is one of the most hazardous components of fission-product contamination. Strontium is chemically similar to calcium, which is one of the major components of bones. Therefore, if strontium is absorbed into the body, following inhalation or ingestion, some of it finds its way into the bones. It remains with an effective half-life of about 16 years, and irradiates the bones all the while.

Strontium contamination, along with other fission-product contamination, is found in fuel storage and hot cell areas. Inhalation of fission products is prevented by proper engineering controls or, when this is not practicable, by wearing respirators in contaminated areas. Ingestion is prevented by washing before eating and by keeping contaminated objects away from the mouth.

4.3.2 Radioiodine

Several isotopes of iodine are produced from uranium and plutonium in reactors. The most hazardous of these is usually iodine-131. Iodine may be released to the air from irradiated fuel if the fuel cladding is damaged. The iodine hazard is particularly severe with fuel that has been irradiated recently. Since iodine-131 decays with an 8-day half-life, the hazard decreases rather quickly with time after irradiation. For example, the amount of iodine-131 in fuel 40 days (five half-lives) after irradiation is only 1/32 of the amount present on the day of removal from the reactor.

I-125 with a half-life of 60 days is produced deliberately by bombarding xenon gas with neutrons in special facilities in reactors.

If iodine-contaminated air is breathed, iodine is absorbed into the body through the lungs. Some of it is then excreted with urine, and some of it is concentrated in the thyroid gland. It irradiates the thyroid gland as it decays.

Inhalation of iodine is prevented by proper engineering controls or if this is not practicable by wearing a respirator whose canister contains charcoal, or an air-supplied respirator. The canisters of the army type and Comfo type of filter respirators used at CRNL contain a suitable charcoal, and are therefore satisfactory for protecting against iodine.

4.4 Plutonium

Plutonium-239 is the most common plutonium isotope. It emits alpha particles (and very weak gamma rays) and unless handled in large quantities does not constitute a significant external hazard. The principal hazard from plutonium arises when it enters the body, by inhalation or through a break in the skin. It then concentrates in bones, where it remains virtually for life. It is possible to take in enough plutonium to result in bone fractures or cancers. Plutonium is by far the most toxic element known to man and must be handled with extreme care. The quantities which are considered hazardous are extremely small and can become airborne quite readily.

Plutonium is handled at CRNL in glove boxes, for example, in the plutonium laboratory in Building 375. It may be in the form of metal, oxide, or in solution.

It can escape from glove boxes and become dispersed in the air if a glove is torn or punctured. Extremely dangerous amounts could be dispersed into the air in the event of a fire or explosion. In such cases, one should never approach the contaminated area without wearing a well-fitted respirator. Do not attempt to work with plutonium until you have become well trained in the techniques commonly recommended. Consult the R. & I. S. Branch before beginning work.

4.5 Tritium

The most common internal contaminant at CRNL is tritium, which is a radioactive isotope of hydrogen. Tritium exists in only minute traces in nature, but large amounts are formed when heavy water is irradiated in the NRX and NRU reactors. Tritium does not emit gamma radiation, and its beta particles do not have enough energy to penetrate the skin. Therefore, tritium is hazardous only when it is inside the body.

The water we drink is a compound of natural hydrogen and oxygen (H_2O). Heavy water is a compound of deuterium and oxygen (D_2O). When heavy water is irradiated by neutrons, some of the deuterium is converted to tritium, resulting in tritiated water of tritium oxide (DTO or T_2O). If heavy water is exposed to the atmosphere after irradiation, some of the tritiated water evaporates and disperses into the surrounding air as tritiated water vapour.

When a person is exposed in an atmosphere containing tritiated water vapour, there are two ways in which the radioactive vapour can enter his body. It may be inhaled and absorbed through the lungs, or it may be absorbed through the skin. The intake by these two methods is approximately equal. Tritium is also absorbed rapidly when the skin is wet with tritated heavy water. In addition, when tritiated heavy water is swallowed, it is absorbed completely into the body.

After being absorbed, through the skin, lungs or digestive system, tritiated water is rapidly distributed throughout the body. It reaches all parts of the body and does not concentrate in any particular organ. The biological half-life of tritiated water, which is the time taken by the body to eliminate half its content of tritium, is about ten days. This half-life can be reduced by increasing the intake of water or other fluids.

Potential tritium hazards exist at CRNL in all locations where heavy water is present. These are mainly in the NRU and NRX reactors and in Building 210 where heavy water is reconcentrated by electrolysis. A tritium hazard may be anticipated whenever opening tanks, drums, piping, pumps or other articles that have contained heavy water. The helium systems associated with the NRU and NRX reactors also contain high concentrations of tritium.

Inhalation of tritium is prevented by proper engineering controls or, when this is not practicable, by wearing an air-supplied mask or hood. Absorption through the skin is prevented by wearing a plastic suit, hood, and gloves.

5. RADIATION EXPOSURE - LIMITS AND MEASUREMENTS

5.1 Radiation Dose Units

The unit commonly used to describe an amount of exposure to X- or gamma-radiation is the roentgen (R), which is named after the discoverer of X-rays. One-thousandth of an R is a milliroentgen (mR). The rate of exposure to X-or gamma-radiation is expressed as mR or R per unit of time (eg. mR/h, R/h, R/min). The exposure rate (or dose rate), multiplied by the exposure time, yields the total dose (eg. mR/h x hours of exposure = mR).

Another unit, the radiation absorbed dose (rad), is used as a measure of the energy deposited in any substance by any type of radiation, including alpha and beta particles, neutrons, and X- and gamma-rays. For X- or gamma-radiation, a rad may be considered as equivalent to a roentgen.

When speaking of radiation absorbed by the body, the "rem" unit is often used, which stands for roentgen equivalent mammal (or man). A rem is the radiation dose, in rads, multiplied by a factor which takes into account the different biological effectiveness of different types of radiation. This factor is called the "quality factor" (QF) or "relative biological effectiveness" (RBE). "RBE" is used for radio-biological experiments, whereas QF is used in radiation protection work. The quality factor differs significantly from one in the case of heavy particles with high energy (such as fast neutrons) or heavy recoil nuclei. The dose in rads, multiplied by the QF, gives the "dose equivalent" (DE) in rems.

5.2 Maximum Permissible Dose (MPD)

An International Commission on Radiological Protection (the ICRP) was set up in 1928. Canada is represented by Dr. C.G. Stewart of the CRNL Medical Division and by Dr. H.B. Newcombe of the Biology and Health Physics Division. Other Canadian experts sit on various committees. The ICRP issues reports in which are set forth the maximum radiation doses which they judge that atomic energy workers and others may receive without exhibiting any effects that would be unacceptable by them or other competent authority. The ICRP also recommends concentrations of radioactivity which can be tolerated in drinking water and in air. These amounts, known as "maximum permissible concentrations" (MPC), are based on the maximum permissible doses. The dose limits in force at CRNL are based on the Canadian Atomic Energy Regulations, which in turn are based on the ICRP recommendations.

5.2.1 External Exposure Limits at CRNL

The limits presented apply to all "atomic energy workers" except when specifically indicated otherwise.

5.2.1.1 Penetrating Radiation (Gamma, X-ray, Neutron)

(a) For the whole body, blood-forming organs, gonads and eyes.

(1) Male "atomic energy workers"

5 rem in any calendar year.

3 rem in any period of 14 consecutive weeks.

0.6 rem in a 2-week dosimeter issue period is an Administrative Control Level and should not be exceeded unless permission has been obtained in advance from the "health authority".

(2) Female "atomic energy workers"

5 rem in any calendar year.

1.4 rem in any period of 14 consecutive weeks.

0.2 rem in a 2-week dosimeter issue period is an Administrative Control Level and should not be exceeded unless permission has been obtained in advance from the "health authority".

(b) For the hands, forearms, feet and ankles

75 rem in any calendar year.

20 rem in any period of 14 consecutive weeks.

4 rem in a 2-week dosimeter issue period is an Administrative Control Level and should not be exceeded unless permission has been obtained from the "health authority".

5.2.1.2 Radiation of Very Low Penetrating Power (Beta, Low-energy Gamma or X-rays)

(a) For the skin of the whole body

30 rem in any calendar year.

8 rem in any period of 14 consecutive weeks.

1.6 rem in a 2-week dosimeter issue period is an Administrative Control Level and should not be exceeded unless permission has been obtained from the "health authority".

(b) For the skin of the hands, forearms, feet and ankles - identical to the doses for penetrating radiation in 5.2.1.1 (b).

(c) For the eyes, when the QF = 1, identical to the doses for penetrating radiation in 5.2.1.1 (a).

5.2.1.3 External Exposure to Neutrons and High Energy Particles

(a) The approximate neutron flux which will deliver a dose of 100 and 300 mrem in a 40 hour week is listed in Table 1.

TABLE 1

TIME-AVERAGE FLUX FOR 40-HOUR WEEK TO DELIVER EITHER 100 OR 300 MREM*

Neutron Energy MeV	$n\ cm^{-2}\ sec^{-1}$ 100 mrem	300 mrem
Thermal	670	2,000
0.0001	500	1,500
.005	570	1,700
.02	280	850
.1	80	250
.5	30	90
1.0	18	55
2.5	20	60
5.0	18	55
7.5	17	50
10.0	17	50
10 to 30	** 10	** 30

* From Handbook 63, U.S. Department of Commerce, National Bureau of Standards.

** Suggested limit.

(b) If sufficiently detailed information on neutron energy is not available, a QF of 10 shall be assumed.

(c) For the lens of the eye, an additional modifying factor may need to be used as well as the QF. The value of the modifying factor should be 3 when the QF is 10 or greater, but should be 1 when the QF is 1. The value of the modifying factor for a QF between 1 and 10 may be obtained by interpolation.

(d) The maximum permissible doses for high energy particles will correspond with those given in the Regulations. The particle flux equivalent thereto will be given by the Radiation and Industrial Safety Branch for any special case. The Radiation and Industrial Safety Branch will obtain approval of this information from the "health authorities".

5.2.1.4 Internal Exposure (All types of ionizing radiation)

The doses permitted for individual organs of the body are based on the recommendations of the ICRP. Some examples of these are given below.

For the Thyroid

30 rem in any calendar year.

8 rem in any period of 14 consecutive weeks.

For the Blood-Forming Organs and Gonads

5 rem in any calendar year.

3 rem in any period of 14 consecutive weeks.

5.2.1.5 Summation of Doses

The radiation dose recorded for an employee is computed by adding the contributions from radiation originating both inside and outside the body. Thus, for example, skin dose may consist of several components, including external gamma dose, external beta dose, and internal dose for tritium. In a second example, the dose to the blood-forming organs may consist of the external gamma dose plus the dose from Sr-90 deposited in bone.

It is usually only practical to add external dose and internal doses due to tritium oxide.

5.2.1.6 Reporting of Dose

The employee is informed bi-weekly of his dose due to external penetrating and soft radiation and when applicable from tritium oxide. On request, the employee may obtain from the Medical Division a statement of his internal contamination. The investigation levels for internal contamination are chosen to correspond to very low levels of dose because of the difficulty in estimating internal dose. Thus, with few exceptions (e.g. tritium oxide), the internal doses corresponding to the urinary and faecal investigation levels represent a very small fraction of the permitted annual dose.

5.2.1.7 Dose Accounting Period

The Canadian Regulations and the Recommendations of the ICRP both use 13 weeks as a basic dose control period. AECL uses a 14 week period for this purpose because dosimeters are processed at two week intervals.

5.2.1.8 Dosimeters

The Regulations require that each employee classified as an "atomic energy worker", and whose radiation exposure may exceed 1.5 rem per year, must wear a film or other acceptable dosimeter while he is at work. At CRNL all employees, all attached staff, and all visitors except certain suppliers' personnel (who never go into the Active Area) are required to wear a photobadge (see section 5.4) and/or other dosimeters provided them.

5.2.1.9 Exposure Records

AECL shall maintain for each "atomic energy worker" a record of his occupational exposure. This record shall not include radiation exposures received in medical diagnosis or treatment.

When employees, not classified as "atomic energy workers", are required to wear photobadges or dosimeters, proper records shall be kept of the exposures.

5.2.1.10 Exposure Permitted Members of the Public

Members of the public, i.e. those not classified as "atomic energy workers" must not receive, in a year, a radiation dose in excess of 1/10 of that permitted an "atomic energy worker".

5.2.1.11 Pregnancy and Radiation Exposure

When an employee who is not an "atomic energy worker" becomes pregnant she may continue to work at her normal job without change in exposure limits providing her Branch Head agrees. He should make his decision on the basis of recommendations of the employee's personal physician and the Plant physician.

When an employee who is an "atomic energy worker" becomes pregnant she may not be permitted to continue in her normal employment. Her Branch Head must ensure, by reassigning her or by other means, that she is exposed at a rate no greater than acceptable for a member of the public during the remainder of the pregnancy.

5.3 Atomic Energy Workers at CRNL

At CRNL the majority of AECL employees and most attached staff are considered to be "atomic energy workers" as defined in the Atomic Energy Control Regulations. The exceptions are listed below and none of these may be exposed at a rate greater than that cited for a member of the general public. The administrative control levels shall be in any two week period not more than 1/250 of the annual exposure permitted an "atomic energy worker".

(a) Visitors who are not "atomic energy workers".

(b) Contractors and their employees who are not "atomic energy workers".

(c) Attached staff whose attachment is for less than one month and who are not "atomic energy workers" in the eyes of their employer. If the attachment is expected to exceed one month they should be made "atomic energy workers".

(d) Non-employees such as truck drivers, telephone repair crews, typewriter and adding machine technicians who make repeated visits of one or two days several times a month or a year, provided their work does not require them to be classified as "atomic energy workers".

(e) Female clerical staff with the exception of those female members of the medical staff who, by the nature of their job, are "atomic energy workers".

The onus is on the Division, Branch and employee who is responsible for an individual of the category listed above to ensure that he or she is classified correctly and not exposed to radiation above the appropriate limits.

5.4 Measuring External Exposure

5.4.1 CRNL Photobadge

The CRNL photobadge contains several devices for measuring radiation exposures, as shown in Figure 1. It should be worn at all times, with the picture side out, on the trunk of the body where the radiation dose is highest. In some situations, it may be desirable to wear dosimeters in more than one location on the body, e.g. on the head, chest, waist, wrist, or fingers.

For many years at CRNL each photobadge contained a film to measure the individual's exposure to ionizing radiation. The film has been replaced by two small lithium fluoride (LiF) thermoluminescent dosimeters (TLD) mounted in an aluminum plaque.

When a thermoluminescent dosimeter is exposed to ionizing radiation, some of the energy of the radiation is absorbed and stored in the thermoluminescent material (LiF). If the dosimeter is heated, this stored energy is released as light. By measuring the quantity of emitted light, the radiation dose can be estimated.

The dosimeters in our badges are used to measure both surface dose (range 10 mrad to 1,000 rad) and whole body dose (range 10 mR to 1,000 R). They are normally read every two weeks but can be read within a few hours if a high exposure is suspected.

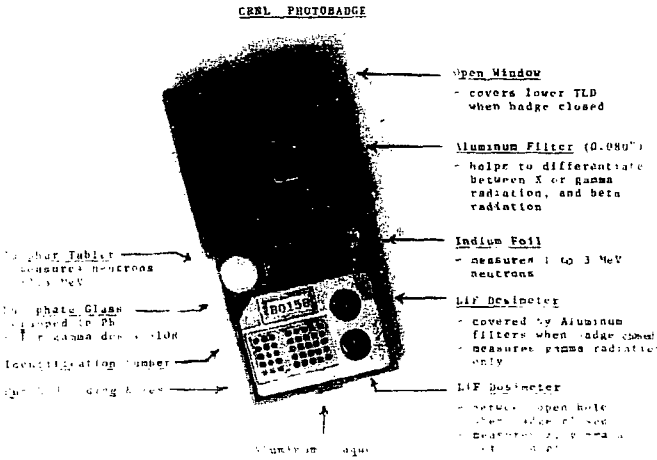
Special thermoluminescent dosimeters made from teflon discs impregnated with LiF are used to measure the surface dose to the hands. They are normally worn in pairs, one on the ball of each thumb (Figure 2).

5.4.2 Pocket Ion Chamber Dosimeter (pencil chamber)

To provide a rapid indication of gamma exposure pocket ion chamber dosimeters are frequently used. They should be worn in the same location as the photobadge. Although the wearer may check his exposure at any time during the day, the dosimeter should be returned to the R. & I. S. Branch office at the end of the shift or work period so that the reading can be recorded. Over exposures can sometimes be averted if the complete record of these readings is kept.

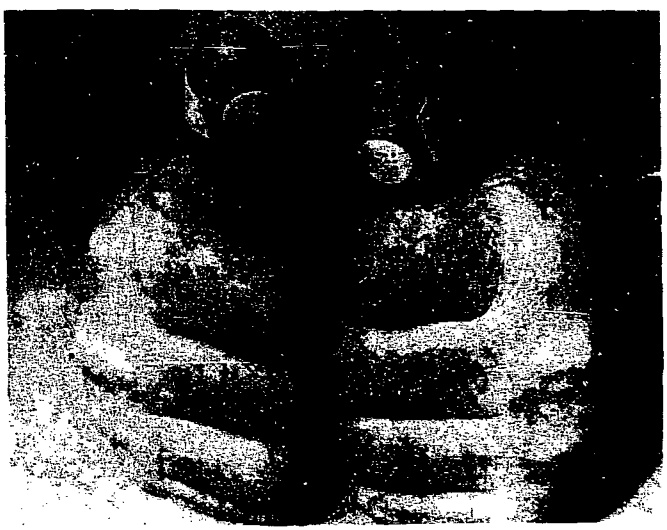
5.4.3 Miniature Warning Dosimeters (AEP 2165A)

In areas where a high risk of radiation exposure exists, workers are often provided with a miniature warning dosimeter. This device gives an audible clicking sound in a gamma radiation



CRNL PHOTOBADGE - Figure 1

- Whole body dose and surface dose are measured routinely once every two weeks.
- Alpha radiation and low energy beta radiation from tritium can not be detected by the photobadge.
- When low-level neutron exposure is anticipated special components must be added to the photobadge (request from R. & I. S. or Health Physics Branch).



CRNL FINGER DOSIMETERS - Figure 2

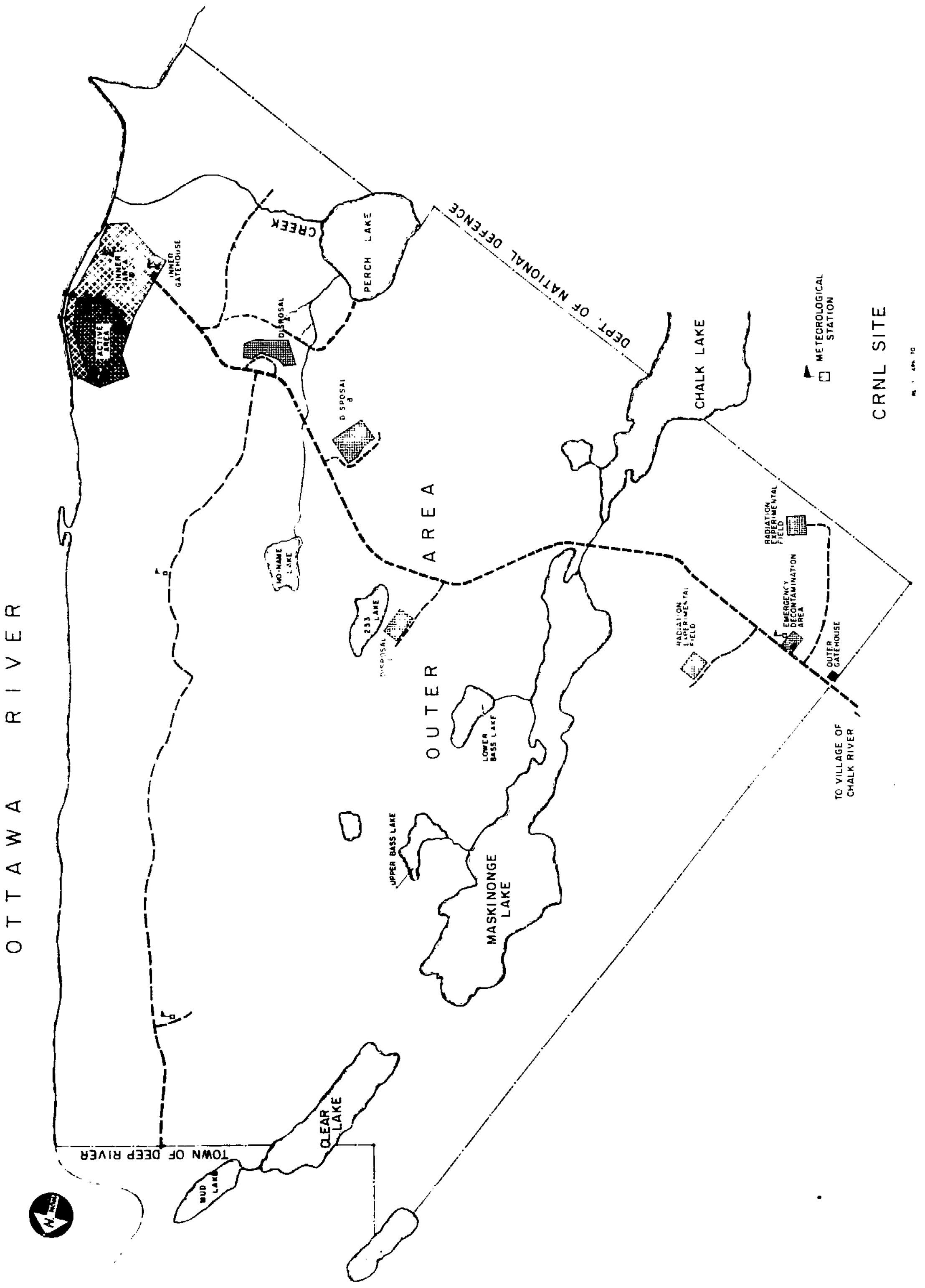
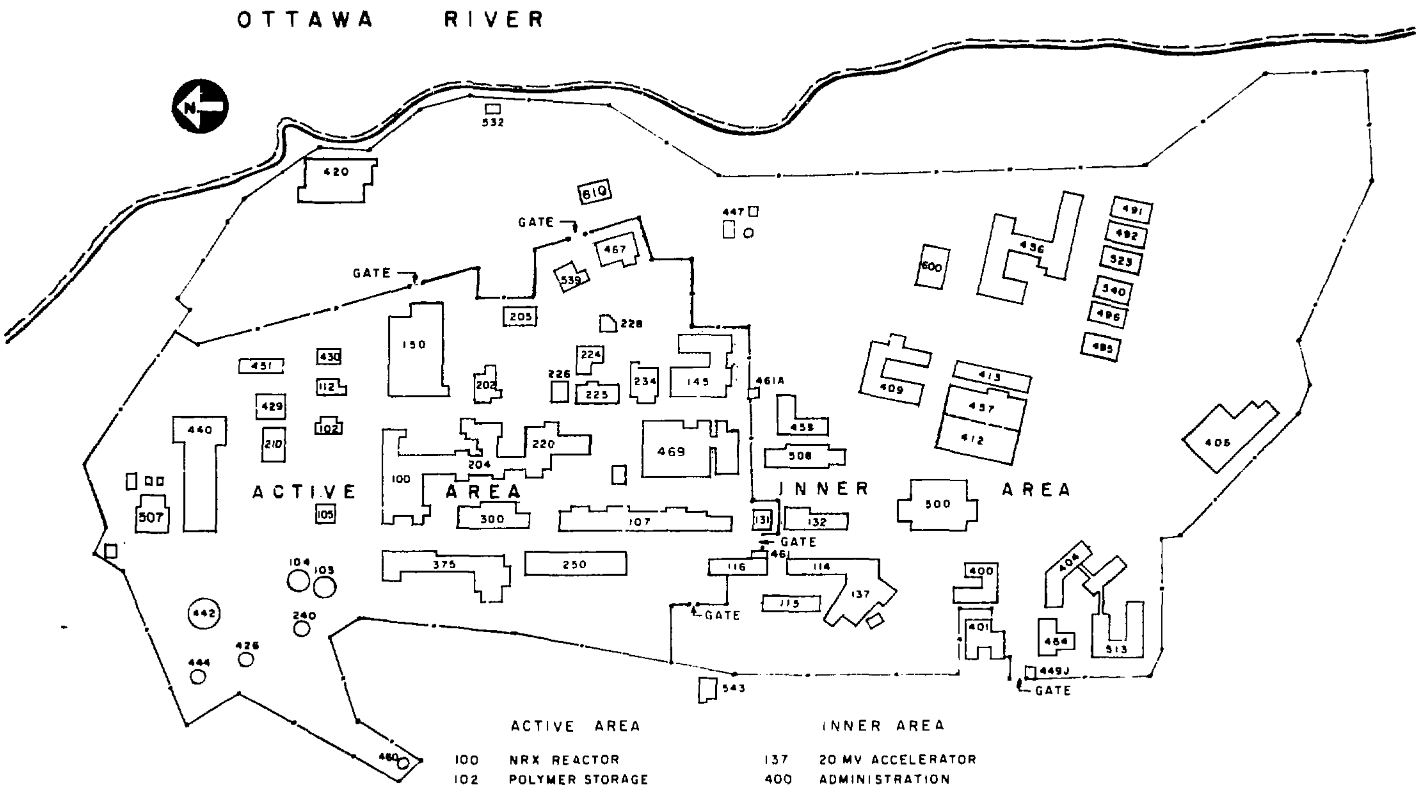

OTTAWA RIVER
OUTER AREA
CRNL SITE
CHALK LAKE
PERCH LAKE
CREEK
DEPT. OF NATIONAL DEFENCE
INNER GATEHOUSE
ACTIVE AREA
NO-NAME LAKE
233 LAKE
LOWER BASS LAKE
UPPER BASS LAKE
MASKINONGE LAKE
CLEAR LAKE
TOWN OF DEEP RIVER
RADIATION EXPERIMENTAL FIELD
EMERGENCY DECONTAMINATION AREA
OUTER GATEHOUSE
TO VILLAGE OF CHALK RIVER
METEOROLOGICAL STATION

FIGURE 3



NRU & NRX STACK

ACTIVE AREA	
100	NRX REACTOR
102	POLYMER STORAGE
105	ZEEP REACTOR
107	RESEARCH CHEMISTRY
112	SPECTROSCOPIC
145	REACTOR RESEARCH
150	NRU REACTOR
202	ACTIVE LAUNDRY
204	NRX ROD BAYS
210	HEAVY WATER UPGRADING
220	49 EXTRACTION
224	COOL WASTE STORAGE
225	ANION EXCHANGE
250	CHEMICAL ENGINEERING
300	DEVELOPMENT CHEMISTRY
375	METALLURGY
429	ROD TESTING AND ASSEMBLY
430	EXPERIMENTAL
440	FILTRATION
461	GATEHOUSE
466	MACHINE SHOP
468	VEHICLE DECONTAMINATION
507	DECONTAMINATION

INNER AREA	
137	20 MV ACCELERATOR
400	ADMINISTRATION
401	GATEHOUSE
409	MAINTENANCE AND CONSTRUCTION
420	POWER HOUSE
447	SEWAGE TREATMENT
456	ENGINEERING
457	PURCHASING AND STORES
461A	GATEHOUSE
464	HOSPITAL
500	CAFETERIA
508	COMPUTERS
513	BIOLOGY AND HEALTH PHYSICS
469	FUEL ENGINEERING
610	ACCELERATOR DEVELOPMENT
507	DECONTAMINATION

ACTIVE AND INNER AREA

REV'T APR. 70

MAIN BUILDINGS SHOWN

FIGURE 4

field. As the intensity of the field increases, the frequency of the clicks increases. When a dose of 200 mR has accumulated, a steady alarm signal is heard.

5.5 Measuring Internal Exposure

Internal contamination is eliminated from the body with the ordinary waste products, urine, sweat, and faeces. By analysing samples of these excreta, usually urine, the amount of radioactive material in the body can be estimated. From this is calculated the radiation dose delivered to the body by that material.

Urine samples are analysed routinely for one or more of the fission products, including radioiodine, or for tritium or plutonium. If a worker is exposed to other radio-elements, a special analysis will be done on request. An overnight sample is required for a fission-product analysis, whereas a small sample excreted at work (a "spot sample") is sufficient for tritium analysis. A faecal sample may be asked for in special cases.

In some cases the internal contamination can be measured directly with a whole body counter. Arrangements for the measurement can be made through the R. & I. S. Branch or the Medical Division.

6. METHODS USED TO PROTECT WORKERS

6.1 Zoning

The CRNL property is divided into three designated areas as shown in Figures 3 and 4.

Outer Area - This consists of all property between the CRNL boundary and the Plant fence. The Disposal Areas are a special part of this area.

Inner Area - All areas within the Plant fence, except the Active Area.

Active Area - This includes reactor buildings, hot cells (caves) research laboratories, chemical extraction plant buildings, and all other buildings at present enclosed by a fence around this area.

Once an object has entered the Active Area, it is considered to be a potential source of contamination. To restrict the transfer of materials back and forth from the one area to the other, some of the equipment in the two areas is duplicated. Sources must be surveyed and properly tagged before movement out of the Active Area, or to another building within the Active Area.

Approval is occasionally granted by the Head of the R. & I. S. Branch or his designate to move contaminated items out of the Active Area, but this practice is discouraged. Items from the Active Area are not permitted to be shipped off the CRNL property unless the contamination level is less than 10^{-4} μCi/cm^2 beta and 10^{-5} μCi/cm^2 alpha (averaged over 300 cm^2) or when properly surveyed and packaged under a license from the Atomic Energy Control Board.

Personnel who work in the Active Area are responsible for monitoring themselves for contamination before leaving their work places. They should not take personal papers into areas where they might become contaminated, and they should have papers monitored if contamination is suspected.

The exits at Building 461 and Building 461A from the Active Area are equipped with corridor monitors which are sensitive to gamma radiation only, and floor monitors which are sensitive to beta radiation as well. The main gatehouse Building 401 is also equipped with corridor monitors. Since appreciable amounts of alpha- or beta-emitting contamination could pass the corridor monitors without being detected, it is important that workers monitor themselves carefully in their own buildings for all types of contamination to which they may have been exposed.

When trucks enter the Active Area to transfer materials from one building to another, plywood liners are placed in their boxes. If contaminated articles are then carried, any loose contamination that falls off will deposit on the plywood rather than on the truck itself. Plywood liners are removed before leaving the Active Area. All vehicles are monitored routinely, or at any time contamination is suspected.

Controlled (Rubber Areas) and Uncontrolled Access Areas

For purposes of contamination control within the Active Area, many of the buildings are divided into controlled access and uncontrolled access sections. Separating the two sections there is usually a rubber station. People entering the controlled access section of a building are required to wear CRNL Active Area safety shoes, or red rubbers, or shoe bags over their personal shoes. Laboratory coats are also required in some buildings.

A complete change of clothing may be required in some Active Area buildings where the contamination potential is great. AECL provides underwear, socks, shoes, cotton coveralls, pants, shirts and laboratory coats. Personal clothing is removed in a changeroom in the uncontrolled access section of the building. Often entry to the controlled access section is gained by walking through a shower room, wearing only wooden or paper sandals. The worker dresses in "whites" and safety shoes before proceeding to his duties. When leaving the controlled access section, the "whites" are removed in the changeroom and the worker proceeds through the shower room in his clogs. Showering is mandatory in some buildings. Building 227 is visited during the course to see the arrangement of a typical Active Area changeroom. The use of hand and foot monitors is also demonstrated.

When areas of high contamination are encountered within the controlled access section of a building, these areas are often isolated by setting up a special rubber area. Since this second area is within a controlled access area, it is called an orange rubber or "double rubber area". Orange rubbers are worn over Plant safety shoes for entry into these areas, or if red rubbers are worn, they are exchanged for orange rubbers when entering the area.

An additional pair of coveralls (double coveralls) or a plastic suit may be required if the contamination level is high. Great care must be taken when removing contaminated clothing to prevent transfer of contamination from the clothing to the skin or hair. When contamination levels are high, it is common for a decontamination operator or monitor to assist with the undressing. Contaminated clothing should be put in paper or plastic bags after removal. Respirators should be kept on until all contaminated clothing is removed and until the undressed worker is about to leave the area. He should be monitored carefully for skin and hair contamination at this point. (See Section 7.3)

6.2 Area Monitors

6.2.1 Fixed Position Gamma Monitors

Radiation levels may change with the transfer of radioactive materials from one location to another. To warn of increased radiation levels, fixed-position gamma monitoring instruments have been installed in many areas of the Plant. Most of these instruments are set to alarm if the radiation level at the detector exceeds 6 mR/h. In locations where the normal background is greater than 6 mR/h, the alarm point is set just above the background level. In NRX, the information from these monitors is recorded in the control room. In NRU, the information is recorded in the control room and is also displayed on meters in the R. & I. S. office.

6.2.2 Ambient Radiation Monitors

Ambient radiation monitors have been installed in several locations at CRNL, at Deep River and at Petawawa, to record variations in background radiation.

6.2.3 High Hazard Radiation Alarms

In areas of the Plant where dangerous levels of gamma radiation are possible, high hazard radiation alarms have been installed. In the reactor buildings, when the radiation field at the detector of one of these instruments reaches a prescribed level a red light flashes and a bell rings. Personnel working in the vicinity should leave until the source causing the high field has been removed.

If the radiation level at the detector rises beyond a higher prescribed level, the red light continues to flash, but an intermittent signal from a "klaxon" horn, operating on a one-second cycle, replaces the bell signal. Personnel in the monitored area must move to a safe location immediately, and must not return until the situation causing the alarm has been corrected, or until measurements have been made to determine safe re-entry procedures.

Should a change in the prescribed levels be desired, no change may be made without the agreement of the Head of the R. & I. S. Branch or his designate.

6.2.4 Criticality Monitors

In areas where fissionable materials are stored or used, "criticality" monitors have been installed, to provide a warning in the event that a neutron excursion or "chain reaction" occurs accidentally. The alarm signal is given by an intermittent klaxon horn, as with the high hazard gamma monitors.

It is absolutely essential that personnel leave the area immediately on hearing a criticality alarm. In some cases, a few seconds delay in leaving the area could make the difference between life and death.

6.3 Air Monitoring

6.3.1 Maximum Permissible Concentration in Air - $(MPC)_a$

The $(MPC)_a$ of a particular radioactive material is that concentration in air to which a man could be exposed for 40 h/wk, week after week, without absorbing sufficient radioactive material to result in an internal radiation dose greater than the maximum permissible dose, which is, for example, 5 rem/yr for the whole body, 30 rem/yr for the thyroid gland and 15 rem/yr for some other organs. Each hour of exposure to 1 $(MPC)_a$ may be considered as equivalent to receiving a radiation dose of 2.5 mrem for materials that irradiate the whole body, 15 mrem for iodine which is concentrated mainly in the thyroid gland and 7.5 mrem for those which are concentrated mainly in other single organs.

It is difficult to measure the concentration of radioactive material in air quickly and accurately; therefore, we must be very careful when using the $(MPC)_a$ values. In practice, this means that respirators are often worn whenever a concentration greater than one $(MPC)_a$ is measured, or whenever a radiation surveyor deems it advisable on the basis of his experience. Respirators are worn during exposure to some airborne contaminants at a CRNL control level that is somewhat different than the $(MPC)_a$ value, as indicated in Table 1.

Tritium is easier to measure than other air contaminants (provided one has a tritium monitor - other survey instruments cannot detect tritium). Therefore, the expected $(MPC)_a$-hours of exposure rather than just the concentration, $(MPC)_a$, is usually the deciding factor when deciding when to wear an air-supplied respirator and plastic clothing. Both are recommended if the anticipated exposure to tritium is greater than about 30 $(MPC)_a$ - hours, or if there is a chance of being wetted with tritiated heavy water. Air-supplied respirators alone are satisfactory if the anticipated exposure is less than 30 $(MPC)_a$ - hours. Air-supplied respirators should be worn whenever working with exposed heavy water regardless of the measured concentration. These recommendations apply to occasional exposures. More restrictive recommendations are required if exposures are frequent.

TABLE 1

$(MPC)_a$'s and CRNL Control Limits (1)

	$(MPC)_a$ dis/(min.m³)	CRNL Control limit dis/(min.m³)
Unknown beta emitters		1,000
Iodine-131 (I^{131})	20,000	7,000
Short-lived beta emitters (half-life about 18 min.)	--	100,000
Tritium oxide (HTO or DTO)	22,000,000 (10 μCi/m³)	22,000,000
Natural uranium (U^{nat})	150	150
Plutonium-239 (Pu^{239})	4	4
Alpha activity, if not known to be uranium	--	4

(1) For more detail consult the Radiation and Industrial Safety Branch.

6.3.2 Air Monitors

6.3.2.1 Moving-Tape Air Monitors

This type is used to detect beta emitting particles in air. A vacuum pump pulls air through a slowly moving tape of filter paper. Dust particles from the air are deposited on the tape. The tape is monitored by a shielded, end-window gieger.

6.3.2.2 Single-Disc Beta Air Monitors

A vacuum pump is used to pull air through a 1.1 inch fiberglass or charcoal-impregnated filter paper, which is mounted in a holder facing an end-window geiger, in a lead shielding castle.

A steel shutter is inserted between the filter and the geiger by a timing device, for a period of two minutes. In this state, the associated ratemeter and recorder indicate gamma background radiation only. Then, the shutter is withdrawn for four minutes. During this time, the ratemeter and recorder indicate gamma background radiation plus any beta activity collected on the filter paper.

If necessary, the radioactivity collected on the filter disc may be examined further, with other radiation measuring instruments.

6.3.2.3 Tritium Monitors

Ion-chamber type tritium monitors are used at CRNL. A vacuum pump pulls air through a filter and an ion trap to remove radioactive dust and ions from the air, and thence through the outer of two concentric ion chambers. The inner, sealed ion chamber responds to any gamma radiation that may be present, whereas the outer chamber responds to both gamma radiation and to tritium oxide (and to other gaseous activity that is drawn into the chamber). The difference in response between the two chambers is due to the tritium oxide (or other radioactive gases). The responses of the two chambers are subtracted electronically, and the difference is registered on a meter calibrated in multiples of the $(MPC)_a$ for tritium oxide.

The AEP-10101 tritium monitor, which is mobile but not portable, can measure tritium concentrations in air, on 10 ranges, from 1 to 30,000 $(MPC)_a$. Portable tritium monitors AEP-1498 and AEP-5215 can measure tritium concentrations in air, on 5 ranges, from 5 to 500 $(MPC)_a$.

Both kinds of tritium monitors will respond to radioactive gases other than tritium. To determine if an indication is caused by tritium or by some other radioactive gas, air is drawn through a tube of silica gel before entering the tritium monitor. Tritiated water in the air is removed by the silica gel, whereas other radioactive gases pass through. Therefore, if the tritium monitor indication falls when the air is passed through silica gel, the indication was due to tritium oxide; if not, the indication was due to some other radioactive gas.

The tritium monitors indicate the tritium concentration in air at any time, but if one wishes to measure the average concentration over a long period, such as an hour or a day, one draws the air at a known rate through distilled water in a glass bubbler. The tritium is washed out of the air as it bubbles through the water. After the desired sampling time, the water is analysed for tritium and the average concentration in air is calculated.

6.3.2.4 Spot Sampler for Beta Emitters

A Staplex air sampler with a 4.2 inch fiberglass filter is used to collect samples of airborne particulate radioactivity. The filter discs are then counted in a scintillation counter and the results are calculated in disintegrations per minute per cubic metre of air, dis/(min.m^3).

6.3.2.5 Iodine

For a rapid spot check for iodine-131 in air, a Staplex sampler using a charcoal-impregnated filter is often used.

For a more accurate estimate of radioiodine contamination in air, a vacuum pump is used to pull air through an Iodine Sample Pack which contains treated copper screens, fiberglass and charcoal-impregnated filter papers, and a cartridge containing charcoal granules. The activity on these collectors is then counted using a gamma-ray spectrometer.

6.3.2.6 Alpha Emitters

For techniques in sampling air for plutonium and other alpha emitters contact the R. & I. S. Branch.

6.4 The Work Permit

A work permit is required before maintenance work is done in most Active Area buildings. The permit is authorized by the Supervision of the building concerned, and is filled out in consultation with a radiation surveyor and a maintenance foreman.

Note:

- There is a time limit stated on the permit. A new permit is required if work is to be continued on the succeeding shift.
- Only the work described on the permit may be done.
- Workers should retain their copy for reference until the work is completed.
- Workers should follow carefully all instructions written on the permit.
- Workers should inform their foreman if they think some hazard has been overlooked.

7. METHODS USED BY A WORKER FOR HIS OWN PROTECTION

7.1 Respirators

When it is necessary to enter an area where appreciable contamination exists, a respirator must be worn. The respirator laboratory is visited during the course to familiarize employees with the types of respirators used at CRNL, and to hear a lecture on the fitting and testing of respirators. Employees return to the respirator laboratory on another day to have respirators fitted and tested.

Two of the respirators, the Comfo and the full-facepiece, are fitted with paper and charcoal filters which purify contaminated air. The full-facepiece respirator is preferred in higher levels of air contamination, or where beta radiation is a hazard to the eyes. The filters of these respirators are effective against dust contamination, radioiodine, and most other vapours, but they are not recommended for protection against tritium.

When tritium vapour is present in the air, protection is provided by air-supplied respirators or hoods. The Willson respirator and the air-supplied hood both obtain air from building air lines. They are used for routine operations. A pressure demand breathing apparatus for use in emergencies or in very toxic atmospheres is supplied from a cylinder of compressed air carried on the user's back.

7.2 Protective Clothing

Cotton clothing is provided for work in areas where slight contamination may be encountered.

Plastic clothing is worn in areas that are highly contaminated with radioactive dust or tritium, or where radioactive liquids or contaminated ordinary or heavy water may spill on a worker. Plastic suits on mannequins are seen during the visit to the respirator laboratory.

7.2.1 Removing Highly Contaminated Clothing

Decontamination operators usually help workers remove their contaminated clothing as they leave "double rubber" areas. The most highly contaminated outer clothing is removed first and is placed in bags. The respirator must not be removed until this has been done.

If there is no one to assist with undressing, and two pairs of gloves were not worn, clean gloves should be put on before starting to undress. Care must be taken to prevent

TABLE 2

ACTION LEVELS FOR FIXED SKIN CONTAMINATION

Beta Contamination Levels	Action to be Taken	Alpha Contamination Levels
Less than 10^{-4} $\mu Ci/cm^2$	Wash thoroughly and remove loose contamination. This level is not a health hazard.	Less than 10^{-5} $\mu Ci/cm^2$
Greater than 10^{-4} $\mu Ci/cm^2$ but Less than 10^{-1} $\mu Ci/cm^2$	Wash thoroughly. During normal working hours, persons contaminated to these levels after thorough washing should proceed to the Plant Hospital for treatment. During other times the worker should present himself for treatment at the first opportunity during normal working hours. (i.e. When the Plant Physician is on duty at the Plant Hospital.)	Greater than 10^{-5} $\mu Ci/cm^2$ but Less than 10^{-3} $\mu Ci/cm^2$
Greater than 10^{-1} $\mu Ci/cm^2$	Wash thoroughly, first. Contamination above this level must be reported immediately to the Plant Physician at all times.	Greater than 10^{-3} $\mu Ci/cm^2$

Note 1: The above action levels apply to fixed contamination which remains on the skin after several attempts have been made to remove it by approved methods. Consult the building radiation surveyor for advice and assistance.

Note 2: In all cases, when a wound or when skin abrasion is associated with the contamination the Plant Physician must be notified and he will advise action to be taken.

Note 3: The averaging area will depend upon detection area of the instrument.

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contaminated clothing from contacting the skin.

7.3 Monitoring

Skin and clothing must be monitored for contamination when leaving a "controlled access" area. A radiation surveyor or a contamination monitor is often available to assist. Rubbers should be removed carefully and placed in the box on the controlled access side of the barrier. Hand and foot monitors should be used as a final check for contamination before leaving the buildings.

If contamination is detected, one should try to remove the activity by washing with soap and water. If skin contamination is still present after washing, advice should be sought from a radiation surveyor. The surveyor might advise a stronger cleaning agent, but it is important that contaminated skin not be injured by harsh cleaning methods. Therefore, the surveyor might recommend that an individual with persistent skin contamination go to the Plant hospital for further decontamination. (See Table 2 for action levels.)

7.4 Remote Handling Apparatus

Gloves will protect the hands from contamination, but not from radiation other than alpha and low energy beta particles. A radiation burn can result from a large dose of radiation. Since the dose rate decreases rapidly with distance from a source, the exposure received can be greatly reduced if remote handling equipment is used.

Adequate protection is often obtainable by using tongs or tweezers when handling small sources. Larger sources are often placed in shielded cells such as those in Building 234, in which all operations are carried out remotely using mechanical arms.

7.5 Safety Habits

Although Supervision and R. & I. S. Branch personnel are concerned with the safety of CRNL workers, they are not always standing by to check if one decides to take a shortcut to avoid some small personal discomfort. Much of the responsibility for safety must rest with the worker. Workers should acquaint themselves with the hazards that exist, and follow the recommended safe practices and procedures.

Smoking - is permitted in the Active Area only in locations known to be uncontaminated and only after hands have been washed and monitored. Smoking is not permitted in "double rubber" areas.

Drinking - in some buildings, the only beverage permitted is water from fountains. In other buildings hot beverages are allowed in certain approved locations, providing the hands are washed and monitored first.

Eating - is not allowed in the Active Area.

Pipetting - of liquids must never be done by mouth.

Wash Often - whenever one works with radioactivity, one should wash and monitor the hands before going to another section of the building, before using a telephone, etc.

Shower - if necessary, and monitor thoroughly before going to lunch, and before leaving for home.

Remember - monitor yourself before leaving your building.

7.6 Procedure in Case of a Known or Suspected Spill

(a) Leave the room in which the suspected spill has occurred.

(b) Remove shoes before stepping into the corridor.

(c) Close the door.

(d) Call for a radiation surveyor, or send someone to get one.

(e) Stand at the entrance to the room to prevent spreading contamination yourself, and to prevent others from entering the room.

(f) The surveyor will check you and your working area for contamination. He will advise you regarding any precautions necessary before normal work can be resumed.

8. FUME HOODS AND GLOVE BOXES

Fume hoods and glove boxes are used to enable workers to handle radioactive materials safely, without spreading contaminatio

Fume Hoods - are used for working with small amounts of relatively low-activity, moderately hazardous material. Work with the window closed as far as possible and do not put your head inside the hood.

Glove Boxes - are usually used for more dangerous radioactive materials, such as plutonium or americium. Glove boxes may also be used for convenience with less dangerous materials. For example, a portable glove box is used to prevent the spread of tritium during fuel rod removal work on top of the NRU reactor.

8.1 Construction and Equipment

At CRNL fume hoods were first built of plywood and glass, and glove boxes were built of plywood and lucite. In later models stainless-steel has replaced the plywood, but many of the original hoods and boxes are still in use. In the earlier models the inner walls were coated with a strippable paint to facilitate decontamination. During recent years the use of ordinary paints, covered with sheet polyethylene, has become more common.

Stainless-steel trays are installed on the floors of fume hoods and glove boxes to prevent the escape of any liquids which may be spilled. Several layers of blotting paper are usually placed in these trays to absorb liquids.

Absorbent tissue (such as Kleenex) provided in a convenient location, is commonly used to wipe pipettes or soak up small spills.

To collect liquid wastes, a plastic bottle, sometimes shielded by lead bricks, is kept in a corner of the fume hood or glove box. Ice cream cartons are convenient containers for dry wastes.

Beta-emitting samples may be shielded effectively by the glass window of the fume hood, by the lucite front of the glove box, or by using blocks of wood with holes bored in them to hold test tubes containing active solutions.

Gamma radiation may be shielded by building a wall of lead bricks around a highly active sample. Good shielding is often obtained by surrounding a sample with lead shot.

8.2 Ventilation of Fume Hoods and Glove Boxes

A constant flow of air must be maintained through a fume hood, to prevent contamination from escaping through the open window of the hood. Air is drawn from the room, through the front of the fume hood, and then discharged, usually through a high-efficiency filter, via a stack to the atmosphere. The air velocity from the room into the fume hood should be between 100 to 250 feet per minute. The flow is checked periodically by R. & I. S. and maintenance personnel.

Glove boxes are kept at a lower pressure than the surrounding room, so that if there is a leak anywhere in the box, room air will be sucked into the box. Glove boxes are fitted with either a manometer or a float gauge to give an indication of air flow. There should be sufficient suction to result in a slight pull on the gloves. If the air flow is insufficient, contamination may escape to the room through leaky joints in the box assembly. If the flow is too great, it will be difficult to work with the gloves.

8.3 Techniques for Using Fume Hoods and Glove Boxes

Moving Materials In and Out

Rubber gloves should be worn for any work in a fume hood. They should also be worn inside glove box gloves as a second protective barrier. Drip trays, polyethylene bags or double containers should be used when moving samples or containers to any location outside a fume hood or glove box.

Removing Wastes

When wastes are to be removed from a fume hood the disposal can should be brought as close as practicable. The waste container should be placed in a clean container as it is removed from the hood. Care must be taken to avoid contaminating the lid of the can with rubber gloves.

Wastes from a glove box may be placed in a clean container through the port of the transfer box. If the transfer box is contaminated the waste container should be placed in a second, clean container as it is removed. The disposal can should be positioned near the outlet of the transfer box to receive the material.

Some glove boxes and transfer boxes are fitted with ports covered by plastic sleeves. Contaminated articles are passed into these sleeves. A seal is made by welding the plastic by use of a slotted clamp and a propane torch. In this way, the contaminated articles are isolated in a sealed plastic bag and at the same time the end of the sleeve attached to the box is sealed.

Changing the Gloves on Glove Boxes

If a glove is punctured, or if a hole develops due to deterioration, the glove should be changed immediately to prevent escape of contamination. Before attempting to change the glove a radiation surveyor should be called to stand by with suitable monitoring instruments. If convenient, the air flow through the box should be increased during this operation.

8.4 Good Working Habits

- Work with the fume hood window down to ensure adequate ventilation and to provide beta shielding. (The air velocity through the open fume hood window should be between 100 and 250 ft/min.)
- Keep samples away from the front of the hood, in case they spill.
- Arrange shielding and other materials away from the front of the hood to reduce turbulence in the air at this point. Turbulence could result in radioactive materials being blown back into the room, rather than being carried up the exhaust duct.
- Keep the fume hood or glove box clean - remove unnecessary equipment. Maintain good housekeeping.
- Shield waste containers (plastic bottles for liquids, ice cream cartons for solids). Remove them as soon as they are full.
- Transfer surplus samples to a storage hood to reduce the chance of spills, and, by reducing the radiation field, to increase the allowable working time.
- Keep your head out of the hood.
- Familiarize yourself with the fire-extinguishing procedures for the particular hood or laboratory in which you work.

9. DECONTAMINATION

Decontamination is the removal of radioactive material from surfaces. Much valuable equipment is salvaged for reuse by decontaminating it.

Decontamination personnel are employed in many Active Area buildings to help control contamination. They conduct swipe checks for contamination throughout working areas on a routine basis. If contamination is encountered, they clean the area immediately, or rope it off until cleaning can be accomplished.

If radioactive material spills or leaks out of some system, high levels of radiation and contamination may result.

In many cases, rooms or equipment must be decontaminated before maintenance groups are able to undertake repairs.

Large items of equipment that become contaminated are usually decontaminated in situ.

9.1 The Decontamination Centre

Items of equipment that become contaminated, if they can be wrapped and transported readily, are sent to the decontamination centre (Building 507) for cleaning. The decontamination centre is visited during the course.

A radiation surveyor or contamination monitor should check all items before they are sent to the decontamination centre. He will advise how the article should be wrapped for shipment, and will attach to it a decontamination tag listing the building of origin, the material, the radiation and contamination levels, and any special precautions to be taken during cleaning. The tag is signed by the owner and by the surveyor or monitor.

Deliveries to and from the decontamination centre are made routinely at a frequency determined by the needs of each building. The driver who transports the article to the decontamination centre returns the bottom portion of the decontamination tag to the owner as a receipt. When the article has been decontaminated it is returned to its owner who returns the bottom part of the tag.

9.2 Decontamination Processes

If an article is only lightly contaminated, it can often be decontaminated by vacuum cleaning or by scrubbing with hot water and detergent.

If an article is heavily contaminated, it is sometimes flushed in a large washer before regular decontamination is attempted. Steam and detergent cleaning has proved effective in many cases. In other cases, soaking in a tank filled with hot water and detergent, agitated with steam has produced good results.

Rubbers and plastic clothing are washed in large commercial washing machines.

The decontamination processes are not always completely effective, so articles are checked for both loose and fixed contamination. A decontamination process tag is attached to indicate the condition of the article after it has been "decontaminated".

A *pink tag* indicates that all loose contamination has been removed. If fixed activity remains, the type and amount are shown on the tag. Since many materials oxidize or corrode slowly in air, one must recognize the fact that fixed activity may become loose over a period of time.

A *red tag* indicates the presence of loose contamination. The location, type, and amount are shown on the tag. If the contamination is on the outer surface, the article will be wrapped before being returned to its owner. The owner must agree to accept it in this condition before it is shipped.

10. DISPOSAL OF RADIOACTIVE WASTES

A major problem created by the operation of an atomic energy plant is the safe disposal of radioactive wastes. They must be stored or buried in such a manner that no significant amount of radioactivity will ever escape.

Solid wastes are classified as active or inactive at the various buildings. Active wastes are suitably packaged and are placed on separate stands, for collection and disposal by the Mechanical Services Branch. The R. I. & S. Branch supervises the collection and disposal to assure that radiation hazards are properly controlled.

10.1 Solid Wastes

10.1.1 Inactive Solids

Most solid wastes from the Inner Area are not contaminated by radioactivity. Many wastes from the Active Area are also inactive. These include waste paper from offices, packing containers from new equipment, and other materials which have not entered the active sections of the buildings concerned.

Wastes that are known to be free of contamination are placed on inactive disposal stands. They are then collected and disposed of in a land-fill dump. Since some may be burned it is important that dangerous materials be separated and identified. This includes items such as empty single-use propane cylinders, aerosol cans, etc.

10.1.2 Collection of Active Wastes and Preparation for Disposal

Laboratories and other buildings in the Active Area, and in some cases in the Inner Area, are supplied with active waste cans. These are usually ordinary garbage cans with an orange band painted around the middle to signify that they are used for active wastes. A plastic bag, or a paper bag with a waxed inner liner, is provided to prevent contamination of the can.

Into these cans are placed dry, low-activity solid wastes. These will include items or materials which have seen service in the active section of Active Area buildings, or in some locations in the Inner Area. When the bags are full, they are sealed with masking tape by decontamination operators, placed on the "active" disposal stands, and are taken to the Disposal Area for burial. Some laboratories are provided with cans with foot-operated lids so that wastes may be deposited in them without touching any part of the can with hands or gloves.

Items for disposal must be packaged in such a manner that they can be handled safely by disposal personnel. There must be no loose contamination on the outer surface of the containers. Extensive use is made of sheet polyethylene or heavy reinforced paper as a final wrapping. Radiation levels must be stated on the forms which accompany each disposal.

10.1.3 Segregation of Active Wastes

Active wastes are segregated according to the radiation level on the waste packages.

If the radiation field measured with a Multi-Purpose Survey Meter (AEP-2153A), with the window open, is less than 100 mR/h at one foot from the waste container, the waste is buried in a sand trench in the Disposal Area. Most of the waste packages contain so little radioactivity that no reading can be obtained on the survey meter. Sand-trench disposals are classified as "routine".

About 10% of the waste packages contain sufficient radioactivity that it is undesirable to bury them in the sand trenches. If the radiation reading one foot from the package is greater than 100 mR/h, the package is normally placed in a concrete-lined trench. Disposals of this type are referred to as "special". The trenches are sealed and covered when they are full.

Some intensely radioactive fuel wastes and other materials such as cobalt-60 are placed in special storage wells in the disposal area.

10.1.4 Precautions in Handling Wastes

Only dry wastes should be placed in disposal cans, since the liners will not contain liquids. The activity level of such material should be low, otherwise workers in the vicinity might be exposed unnecessarily to radiation.

When removing dry wastes from a fume hood or glove-box, first put them in a clean container (ice cream carton; polyethylene or paper bag) in the fume hood or glove-box. Bring the disposal can as near as practicable to the material that is to be thrown away. Do not carry active wastes from a fume hood on one side of the room to a disposal can on the other side of the room. The chances of spreading contamination are too great.

Disposal cans should not be handled while wearing contaminated gloves. Remove the gloves or else cover the handles with kleenex or some other suitable material before touching the disposal can.

10.2 Liquid Wastes

10.2.1 Inactive Liquids

Storm sewers in the Inner and Active Areas carry surface drainage directly to the Ottawa River.

Sanitary sewers in the Inner and Active Areas carry inactive wastes from wash rooms and some other building drains to the sewage treatment plant, and thence to the river.

No radioactivity may be deliberately disposed of in these systems without authorization by the Chalk River Environmental Authority.

10.3 Low Activity Liquids

10.3.1 Disposal to the River

Operation of the NRX reactor requires approximately 3200 gallons of water per minute to cool the fuel rods. The cooling water is slightly radioactive after passing through the reactor, due to neutron activation of oxygen and impurities. To permit the decay of short-lived products, the cooling water flows through two delay tanks before it is discharged to the Ottawa River.

Wastes from the laundry, and condensate from some evaporators, are passed directly to the river via the process sewers.

Wastes from the decontamination centre are collected in a holding tank. They may be discharged to the river or pumped to a seepage pit in disposal area, depending on the level of activity.

10.3.2 Disposal to Seepage Pits

The waste farm disposal system consists of collection tanks

(Building 242, 243) for wastes from active drains, a pumping station (Building 240), two underground disposal lines and seepage pits near the "A" Disposal Area.

The average volume of wastes handled from the NRX and NRU reactors is around 600,000 gallons per month. The average volume from the chemical and research areas is around 200,000 gallons per month.

10.3.3 Emergency Disposal Pit

In the event of an incident necessitating the storage of a large volume of contaminated water, an emergency storage pit is available in the Outer Area. This pit is dug out of the sand and is lined with sheet polyethylene. It can retain 1,000,000 gallons of water, which can be pumped in by a pipeline from the liquid waste disposal system.

10.4 High Activity Liquids

10.4.1 Storage in Tanks

Several thousand gallons of high activity liquid wastes accumulated from the operation of the Chemical Extraction Plant. This plant recovered plutonium from the NRX fuel rods, but has not been operated for this purpose for some years. The liquid wastes are now stored in the Outer Area in underground stainless steel tanks. Some wastes have been evaporated to reduce their volume.

An ion exchange plant is operated in Building 200 to deionize water from the NRX and NRU fuel storage bays. Approximately 100,000 gallons are processed per day and returned to the bays. The ion exchange columns are regenerated periodically. The contaminated regenerants are evaporated and stored in tanks.

Wastes from some of the storage tanks have been mixed with concrete, placed in steel drums, then sealed in a concrete monolith in the disposal area.

10.4.2 Laboratory Wastes

Small volumes of radioactive liquid waste result from analytical work and other procedures. The discharge of these wastes to the seepage pits is discouraged. They should preferably be solidified and stored in that form in the Disposal Area. The R. & I. S. Branch should be consulted.

10.5 Gaseous Wastes (See also Section 3.2)

The cooling air from the NRX and NRU reactors contains argon-41 whenever the reactors are operating. Fission-product gases are occasionally present in the cooling air too, even if the reactors are shut down. Since these gases are short-lived, and are only mildly hazardous compared with some other radioisotopes, they can be discharged safely to the atmosphere in controlled amounts. However, they must be well diluted with atmospheric air to prevent unacceptable concentrations being encountered by people in the neighbourhood of the discharge. To accomplish the necessary dilution, the gases are discharged out a high stack, one half mile from occupied areas of CRNL.

Reactor cooling air is passed through high efficiency filters before being discharged up the stack, to remove any radioactive particles that might be released from the reactors.

Several smaller, lower stacks are used to discharge small quantities of radioactive gases from various CRNL laboratories. Those which could release dangerous radioactive particles are equipped with high efficiency filters and, where appropriate, charcoal filters for the removal of radioiodines.

11. EMERGENCY PROCEDURES (See Standard Policies and Procedures 0-1)

A STAY-IN EMERGENCY is called when the health hazard requires everyone, unless otherwise instructed, to proceed or remain indoors.

An EVACUATION EMERGENCY is called when the health hazard requires everyone, unless otherwise instructed, to leave the site.

A HEALTH HAZARD requiring Stay-in or Evacuation might result from:

(a) A high radiation field,

(b) The release of radioactive or other contamination into the atmosphere in the form of gas, smoke or dust,

(c) A fire from which (a) or (b) might result.

Any employee who believes conditions require a STAY-IN shall report immediately to his supervisor who, if he agrees, shall call local 700 and report the circumstances, the building number and Branch to the NRX CONTROL ROOM ATTENDANT. The employee may take this action himself if his supervisor cannot be located immediately.

STAY-IN - A rising and falling signal on the emergency sirens (lasting for 2 minutes).

(a) Remain in, or go into the nearest building.

(b) Close all doors and windows.

(c) Follow any special building instructions.

EVACUATION - A continuous signal on the emergency sirens (lasting for 2 minutes).

(a) Unless specifically instructed to remain, prepare to leave the laboratories.

(b) Leave your building safe - turn off electrical appliances, close doors and windows.

(c) Proceed to the bus platform with a folded handkerchief or several kleenex tissues over the nose and mouth.

(d) Walk - do not panic.

(e) You will be checked for contamination at the dispersal area near the outer gate.

ALL CLEAR - A series of intermittent blasts on the Plant whistle (lasting for 2 minutes).

This indicates that the emergency has passed and that normal work may be resumed.

APPENDIX A

AECL Health and Safety Organization

The Health and Safety Organization of Atomic Energy of Canada Limited is set forth in AECL publication AECL-1027 (seventh edition, 1973):

"Responsibility for the health and safety aspects of all operations of Atomic Energy of Canada Limited lies directly with management. Management is guided, however, by the advice of certain senior staff, divisions and committees whose functions are to specify the precautions to be taken."

Some of the advisory groups whose functions are important to safety at CRNL are:

- CRNL Safety Committee
- AECL Safety Committee
- Nuclear Safety Advisory Committee
- CRNL Criticality Panel
- Accelerator Safety Committee
- Chalk River Environmental Authority and Chalk River Environmental Panel
- Biology and Health Physics Division, CRNL
- Medical Division, CRNL
- General Services Division, CRNL
- Administration Division, CRNL

The membership and functions of these groups are given in the annexes of AECL-1027.

The Radiation and Industrial Safety Branch of the General Services Division is charged with the administration of company policy with regard to all radiation safety matters at CRNL. The various regulations that have been drawn up are contained in Standard Operating Policies and Procedures, and in the Health Physics Manual. These reports are available in branch offices in the Active and Inner Areas.

APPENDIX B

RADIATION AND INDUSTRIAL SAFETY BRANCH OFFICES

Main Office:

Head	L.C. Watson	Local 385 (Bldg. 513)
Health Physicists	J.M. White	Local 280 (Bldg. 513)
	J.M. Werry	Local 500 (Bldg. 513)
	G.R. Edwards	Local 500 (Bldg. 513)
	J.A. MacNeil	Local 280 (Bldg. 513)
Safety Engineer	G.E. Crispin	Local 447 (Bldg. 513)
Safety Office	D.V. Peplinskie	Local 447 (Bldg. 513)
	D.A. Millark	Local 447 (Bldg. 513)

Area Supervisors:

NRU Reactor	A.O. Furness	Local 622 (Bldg. 150)
NRX Reactor	T. Robertson	Local 329 (Bldg. 100)
Research Areas	R.J. Beal	Local 554 (Bldg. 375)

Solid Waste Disposal

A.E. Russell — Local 586 (Bldg. 430)

R. & I. S. Branch Area Offices		Bldg.	Local
- Active Area Gate		461	494
- Chemical Extraction Area		220	477
- Chemical Operations Hot Cells		234	271
- Chemistry Area		107-250	365-396
- Decontamination Centre	Foreman: W.H.A. Wagner	507	551-588
- Development Chemistry		300	591
- Emergency Stores R. & I. S.	Foreman: W.H.A. Wagner	507	594
- Filter Testing		430	679
- Information		513	293
- Instrument Pool	J.H. Fenn	225	292
- Metallurgy		375	554
- NRU		150	622
- NRX		100	329
- Respirator Laboratory	K.W. Merrett	507	594
- R. & I. S. Development Laboratory	K.W. Merrett	430	679
- Training Room	J.H. Fenn	225	292

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