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Determination of removal factor of an indirect contamination measurement using the exhaustion method

DEGREE PROGRAMME OF ENERGY AND ENVIRONMENTAL ENGINEERING
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ABSTRACT

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The removal factor is a parameter of measuring radioactive contamination from surfaces with an indirect measurement. It is the most difficult parameter to evaluate since it is affected by several variables from human differences and error to the material being investigated. The conservative value traditionally used for the calculations in instrumentation is 10%.

The goal of the thesis is to determine the removal factor using the quantitative method on several different surfaces, with contamination bound on different kinds of conventional dirt, with the aim to test the conservative value of 10%. A number of smear samples shall be taken by several individuals from contaminated surfaces. The surface shall be wiped until all the contamination is exhausted. The activity captured by the first sample shall be compared to the cumulative activity in all the samples; this ratio is referred as the removal factor.

If a higher value can be shown to be valid, the result will be more accurate contamination measurements. This would lead to decreased time and other resources being used to decontaminate, measure out and free release material from controlled areas.

If values below 10% are recorded, it may indicate that it is possible that the instrumentation reading the samples is providing values that are too low. This would mean that contamination with values over the limits might end up being handled with insufficient radiation protection measures.

Due to practical limitations of other work by our staff, sufficient data could not be produced to execute a significant research. The results indicate to support

the use of the conservative value of 10% for the removal factor, but further research is needed to challenge the use of this value.

Keywords: nuclear energy, contamination measurement, instrumentation, removal factor.

CONTENTS

SYMBOLS AND TERMS

ALARA = As Low As Reasonably Achievable

EPR = European Pressurized Reactor

IAEA = International Atomic Energy Agency

ICRP = International Commision on Radiological Protection

STUK = Radiation and Nuclear Safety Authority (Säteilutyrvakeskus)

WHO = World Health Organization

A_s = Activity measured from the surface [Bq/cm^2]

η = measured count rate [s^{-1}]

η_B = background count rate [s^{-1}]

ε_i = detector efficiency for the radionuclide being investigated

ε_r = removal efficiency

ε_s = efficiency of the contamination source

S = surface area being examined [cm^2]

1 INTRODUCTION

The goal of the thesis is to experimentally determine the removal factor for an indirect contamination measurement using dry smear samples. The indirect method is generally used in nuclear power plants when the background radiation is high enough to prevent performing direct measurements reliably, or if the surfaces in question are not accessible with detectors due to tight spaces.

The removal factor is one of the parameters programmed in instrumentation that measure surface contamination indirectly. It evaluates how much of the existing non-fixed, or loose, contamination is picked up by the sample smear. The generally used, conservative value for removal factor is 10% (Standardiseringskommissionen i Sverige, 1990, page 6). The aim of this thesis is to assess the validity of this presumption.

The study was commissioned by a Swedish company Nutronic AB, which specializes in manufacturing, maintaining and selling instrumentation used to detect and measure radioactivity. This thesis is meant to further the study ”Experimental Determination of Contamination Removal Factors Associated with Cotton Smear Samples” (Monto, 2020). In the aforementioned study the removal factor was determined by utilizing an artificially contaminated surface where 100% of the contamination was assumed to be removable. The activity absorbed to a single smear sample was compared to a direct measurement of the surface being surveyed. The study accounted for non-transferable or fixed contamination by ensuring that the contaminated surface was decontaminated between wipes, however, due to the use of chemical agents in the decontamination process, the true extent of the fixed contamination may have varied, and consequently affected the conclusions of the study. In this study we utilize a different method, which is more representative of the actual

conditions wherein loose contamination is found inside nuclear power plants, by taking smear samples from the surface until it is exhausted of all transferable, or loose, activity. The activity in the first sample will be divided by the cumulative activity in all of the samples and this ratio is called the removal factor. (Standardiseringskommissionen i Sverige, 1990, page 4). The human error and differences in sample taking will be minimized by using tape to mask off an exact surface area to ensure correct sample size, and several people executing the measurements to average out the differences in the pressure used when taking samples.

2 RADIOACTIVITY

Radiation is energy moving in the form of waves or subatomic particles and we are always exposed to it. In the case of wave-like, i.e. electromagnetic radiation, when the wavelength decreases, the energy carried by the radiation increases. Particle radiation, on the other hand, is energetic by way of kinetic energy.If radiation carries enough energy, it has the ability to remove electrons from atoms or molecules. This is called ionizing radiation. (Centers for Disease Control and Prevention, 2024).

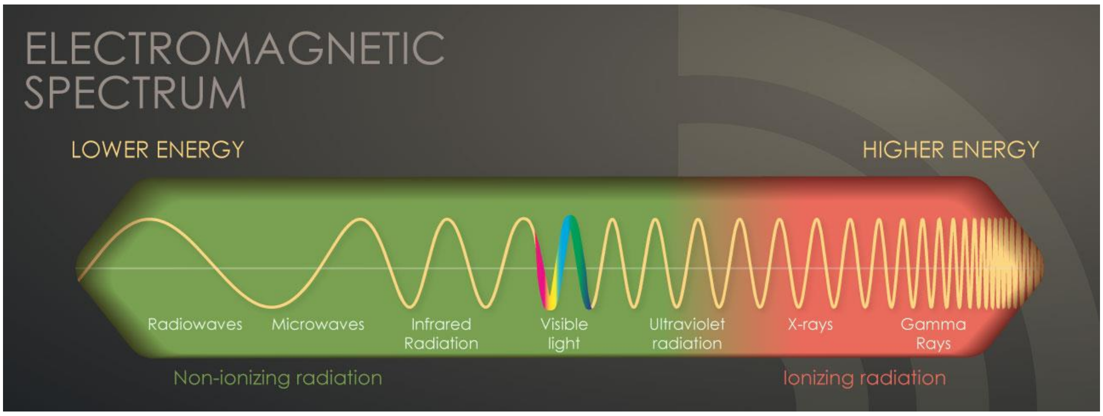

Figure 1. Non-ionizing and ionizing radiation on the electromagnetic spectrum. (Centers for Disease Control and Prevention, 2024).

The main types of ionizing radiation in a nuclear power plant environment are gamma radiation, neutron radiation, alpha particles and beta particles.

Alpha particles are Helium nuclei emitted from heavy nuclides, such as Uranium-238. Therefore, in nuclear reactors, alpha radiation is found inside the fuel rods in the form of uranium and activated transuranic elements, such as plutonium, neptunium and americium, as well as places that have been in contact with nuclear fuel based contamination. Alpha radiation has low range in air and it is easily stopped by medium, even such as paper or skin. Therefore alpha radiation is not a serious external hazard. Radioactive materials that emit alpha particles are the most hazardous when they become internal contamination, through ingestion, inhalation, absorption or through open wounds. Alpha particles cause ionizations in cells that are close together, and as such, can cause more severe damage to the biological organisms they transfer their energy to. Therefore, the use of personal protective equipment, alpha measurements and other safeguarding measures are needed when working with the possibility of alpha contamination. (Säteilyturvakeskus, 2002, page 20)

Beta particles are electrons or positrons, fast and small particles with a negative electrical or positive charge. Beta decay can happen by electron capture, β^+-decay or β^--decay, although only the latter two mechanisms produce beta particles. Beta particles are dangerous if they come into contact with skin and especially the eyes. They will not penetrate a layer of work clothes. Cesium 137 and Strontium 90 are among the most common beta-emitting nuclides in nuclear power plants. Similarly to alpha emitting radionuclides, beta contamination also presents a significant hazard when taken inside the human body, which is why good monitoring and control measures are of central importance in protection against non-fixed radioactive contamination. (Säteilyturvakeskus, 2002, page 21)

Gamma radiation is ionizing, electromagnetic waves consisting of photons, packets of energy with no mass. Gamma rays have high penetration power, and they need to be shielded with heavy elements such as lead. Gamma

radiation is a hazard both externally and internally. The main methods of reducing gamma dose is to minimize time near the source, maximize the distance to it and add shielding between personnel and the source. Cobalt 60 is a commonly met nuclide and a significant source of gamma radiation in light water reactor facilities. (Säteilyturvakeskus, 2002, page 17)

Neutron radiation is indirectly ionizing. Neutrons have no charge and thus don't ionize in the same manner as charged particles such as electrons or protons, but the neutron interactions are ionizing. Neutron radiation is also able to turn the affected matter radioactive through a process called neutron activation, which often gives rise to alpha, beta and gamma radiation events. Neutron radiation is more penetrating than gamma radiation in some circumstances. (Säteilyturvakeskus, 2002, page 49)

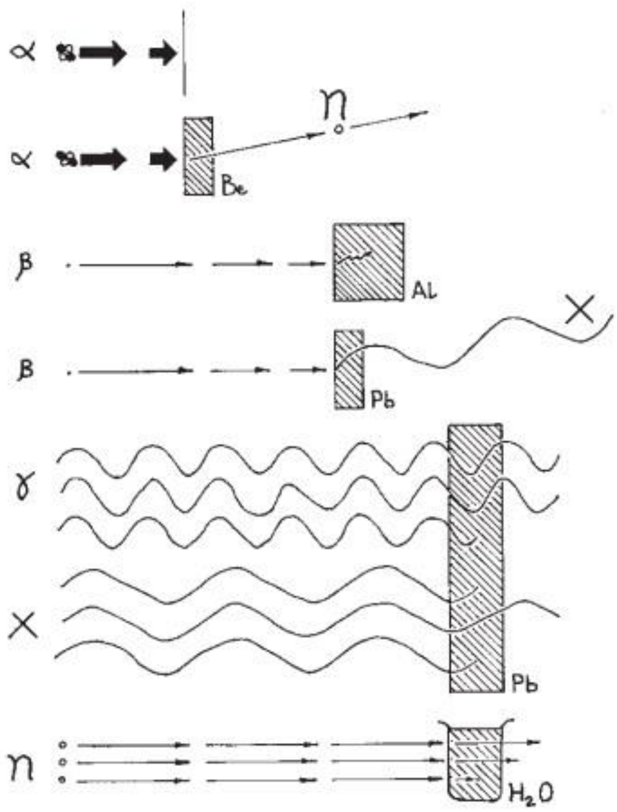

Figure 2. Penetration powers of alpha and beta particles and gamma-, x-ray- and neutron radiation. (International Atomic Energy Agency, 2014, page 5).

Figure 2 illustrates how different kinds of radiation can be shielded. Low-density materials, such as aluminum, are a good shield against particles like

alpha and beta. High density material (lead, concrete) are effective in shielding against photons like gamma and x-rays. Hydrogenous materials such as water, polyethylene and concrete slow down neutrons and offer good shielding against it. It is noteworthy that interactions high-energy with alpha particles can be used to produce neutrons from beryllium. (Tomberlin, 2014, page 10). High-energy electrons, such as beta particles, may create bremsstrahlung radiation on impact with high-density shielding such as lead. The x-ray photons created as a consequence may be more harmful to living tissue than the original beta particles.

3 CONTAMINATION

The IAEA (International Atomic Energy Agency) defines radioactive contamination as follows:
“Radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places.”
(International Atomic Energy Agency, 2007, page 41)

Most of the unintended activity, or contamination, in nuclear power plants is either fission products or activation products. Fission products are fuel-based nuclides formed in the splitting of the heavier nuclides in the reactor core. Activation products are impurities in the reactor coolant that got activated in the neutron flux.

Contamination can occur as radioactive particles in any medium. It can land on any solid surface, it can be bound in particles inside liquids or gases, such as water and air.

Contamination on surfaces can be either transferable or non-transferable. Transferable contamination, also called loose or non-fixed, means that the

contamination can be removed from the surface during routine activities or transport. Non-transferable, or fixed contamination, doesn’t come off the surface unless it’s subjected to abrasive work. In work environments surface contamination is often a mix of both loose and fixed.

4 HEALTH EFFECTS

The health effects of ionizing radiation can be divided in two categories: deterministic and stochastic. Deterministic health effects are a consequence of large radiation exposures that happened in a short time. Stochastic effects on health are probabilistic, which means the probability of adverse hereditary health- or carcinogenic effects as a result of low amounts of DNA damage. All deterministic effects are somatic, which means they occur in the individual that was exposed to radiation. Stochastic effects can be somatic or they can be hereditary.

Deterministic effects of ionizing radiation are directly related to the radiation exposure, and the effects of radiation are proportional to the absorbed dose received. A deterministic effect has a threshold leading to cell death. There is great variance between individuals in when they experience effect from radiation, but it is in the area of magnitude of 0,1Gy. (United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 1993 Report to the General Assembly with Scientific Annexes, 1993, page 14).

Stochastic health effects are probabilistic in nature, which means that the likelihood of health consequences, such as heritable mutations or cancer, increase with the dose a person is exposed to. Because of the low increase in risk, the causality can only be shown in a statistical form and individual cases can not be assigned to exposure incidents even if the doses received are known. (United Nations Scientific Committee on the Effects of Atomic

Radiation UNSCEAR 1993 Report to the General Assembly with Scientific Annexes, 1993, page 227).

Almost all cancers can be attributed to a compound effect of carcinogenic exposure, but certain types of cancer occur in increased numbers for given radiation doses. A cell's regeneration speed is linked to the amount of damage it will receive from radiation. Cells that regenerate fast are more likely to form cancer or experience other negative health effects. For the same reason young people and children are more prone to suffering cellular damaged from ionizing radiation, and this is why pregnant women have a dose limit of 1mSv during pregnancy, when normally radiation workers have an annual limit of 20mSv/h. Many nuclear power stations prohibit pregnant women from entering the radiologically controlled area altogether. (International Atomic Energy Agency, 2014, page 63).

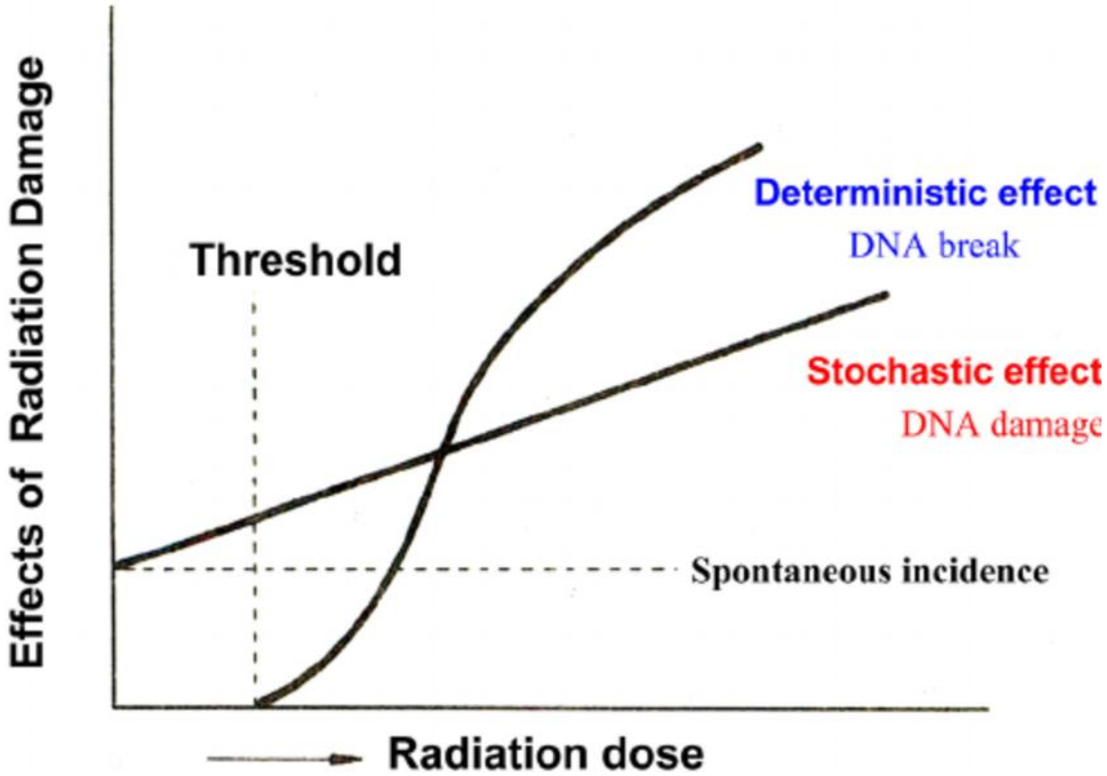

Figure 3. Classification of effects of radiation damage. (The Keio Journal of Medicine, 2012).

Much of the data has been taken from studies conducted to the victims of the Hiroshima and Nagasaki bombings. The risk of cancer was plotted against the

dose received, resulting with a presumed linear correlation between the two. The natural incidence of cancer masked any cases that may have been inflicted by the radiation under the lowest data point, so it cannot be said for sure if low doses cause a health risk. (United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 1993 Report to the General Assembly with Scientific Annexes, 1993, page 15).

For the purpose of industrial radiation safety, a conservative theory of a Linear Non-Treshold (LNT) model has been taken into use. It means any increase in dose received increases the risk of adverse health effects.

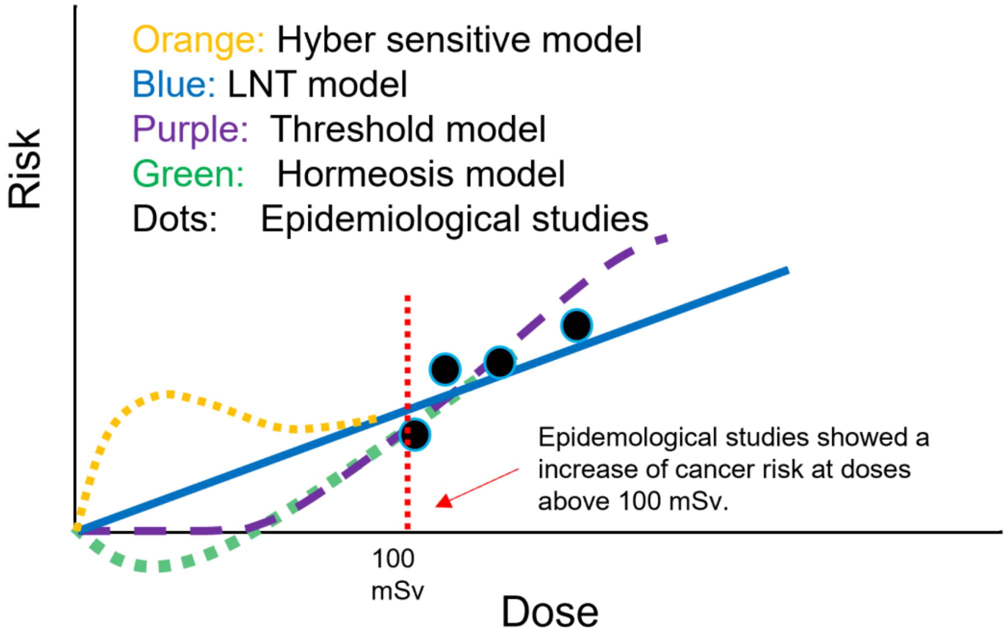

Figure 4. The linear no-treshold model presented in blue. (World Health Organization, 2017).

The negative health effects from direct ionizing radiation are external. From contamination exposure they can be external or internal. If the contaminants land on a person’s skin, hair or clothes, it is considered an external hazard. It will affect the person as long as it remains on them, but it can be wiped or cleaned off of them and they will not be affected by it any longer. If the

contamination finds its way into the person's body, it will be considered internal contamination. This can happen through inhalation, ingestion, absorption or through open wounds. The time to get rid of the source of activity in one's body is called the effective half-life, which takes into the account both the physical half-life (the rate the nuclide loses its activity due to decay) and the biological half-life (the rate compounds decrease in one's body due to sweating, urinating etc). (International Atomic Energy Agency, 2018, page 22).

4 POWER PLANT STRUCTURE

A layout of the Areva-designed EPR will be used as an example of how contamination forms in a nuclear power plant.

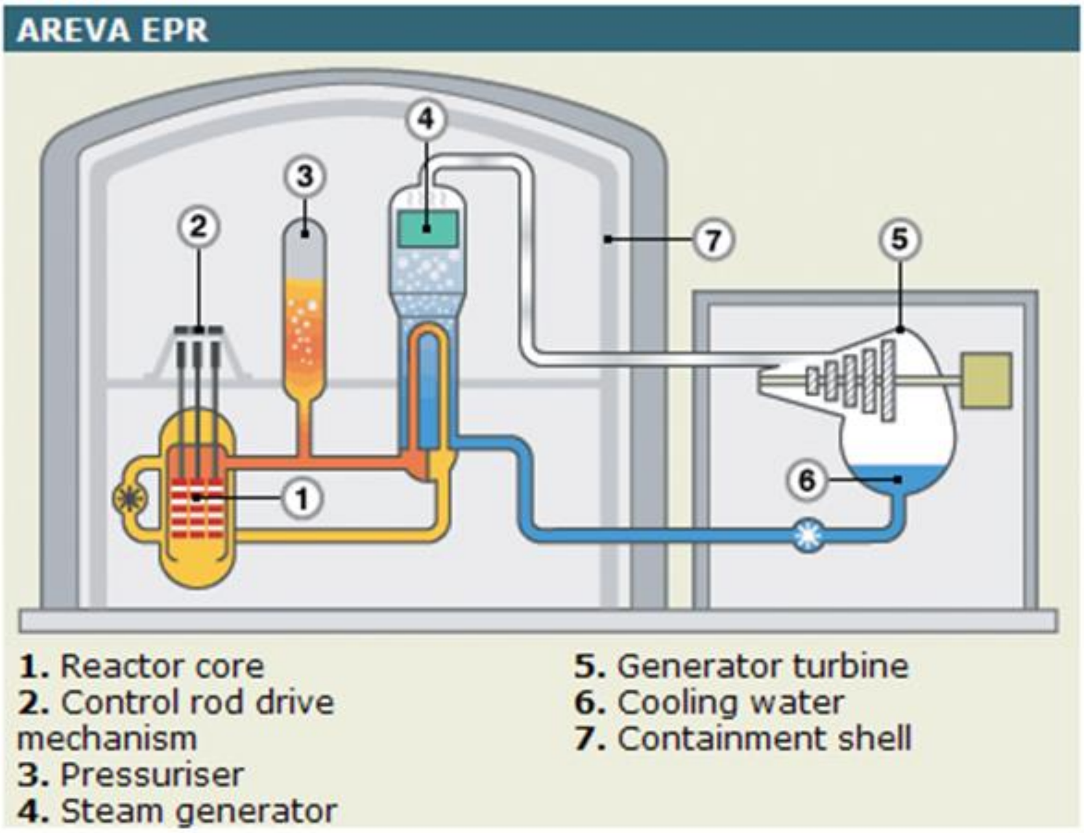

Figure 5. Main component of a European Pressurized Reactor, Areva design. (Neutron Bytes, 2023).

Above is the power plant diagram of a European Pressurized Reactor (EPR) design by Areva. It consists of primary circuit marked with orange color, and the secondary circuit marked with blue and gray. The reactor core (1) heats up the water in the primary circuit which is kept in liquid phase by utilizing the pressurizer (3) to maintain the system in high operating pressure. The water is driven to a large heat exchanger called the steam generator (4), where the hot primary side water gives its heat to the secondary side water in lower pressure, turning it into steam which is pumped to the turbine (5). This kinetic energy is then turned into electricity in the generator. The steam is condensed back into water with cooling water (6), and pumped back to the steam generator.

Theoretically, all the radioactivity of the nuclear fuel is supposed to stay within the fuel rods in the reactor. In practice, however, imperfections in the fuel rods are not uncommon and may result from foreign material in the coolant, corrosion, thermal stress, manufacturing defects, and several other causes. In addition, due to the process of neutron activation, which affects the coolant water and the microscopic debris that is continually introduced to it by corrosion of the primary circuit structures, contamination of the primary circuit cannot be avoided even if the fuel cladding retains its integrity. This radioactive contamination is spread in the primary circuit and the systems attached to it. Because the primary side isn’t in direct contact with the secondary side, the contamination should stay on the primary circuit and system in contact with it. If there are primary tube ruptures in the steam generators, the contaminants can spread to the secondary side. (Teollisuuden Voima, 2024, page 5).

Contamination can be controlled and minimized through design criteria and operating procedures. It can also be made easier to decontaminate. In the design phase, we can choose materials that do not corrode or absorb neutrons easily. On the operational side we can control the chemical properties of the coolant to minimize radionuclide transport with, for example, boron volume and corrosion rate (International Atomic Energy Agency, 1981, page 11). Crud in the coolant can be filtered out with specific purification installations.

In an operating power plant, contamination can be controlled with work planning and the use of personal protective equipment. (International Atomic Energy Agency, 1996, page 23).

There are several different kinds of nuclear reactor types used for generating electricity, but they all operate by heating water and producing steam that drives the turbines. Pressurized water reactors account for 70% of the commercial reactors in the world and boiling water reactors 15%. (World Nuclear Association, 2024).

5 LEGISLATION AND INSTRUCTIONS

The use of radiation in Finland is guided by laws, regulations and guidelines set up by the national Radiation and Nuclear Safety Authority (STUK – Säteilyturvakeskus). International law and EU directives must be taken into account. (Säteilyturvakeskus, 2024).

The Radiation Act focuses on protecting workers and the general population from unplanned radiation exposures and aims to reduce the environmental impact of the use of radiation. Medical radiation use, applied use of radiation in different industries and radiation related research fall under the legislation of the Radiation Act.

The Nuclear Energy Act ensures that the use of nuclear energy is a net benefit to the society as a whole throughout its whole life cycle. It has to be safe to the workers, the general population and the environment. It must not enable the spread of nuclear weapons.

STUK provides regulations and guidelines to ensure the safe use of radiation in power plants and other fields. Some of the guidelines are binding to the

holder of the license to use radiation, others are regulatory guides that leave more discretion to the license holder.

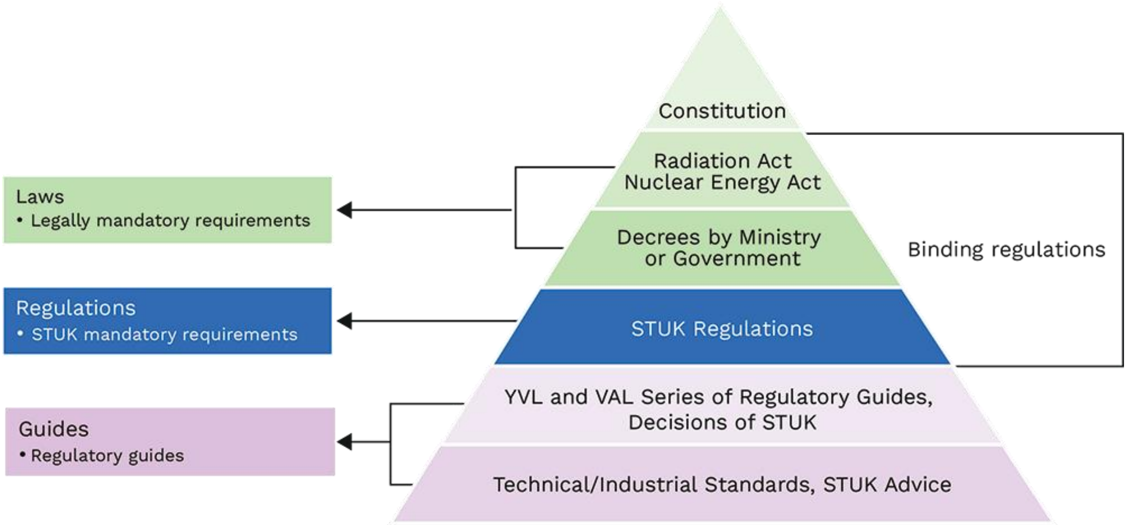

Figure 6. Laws, regulations and guides regulating the use of radiation in Finland (Säteilyturvakeskus, 2024)

As dictated by the Radiation Act, three principles must be met to justify the use of radiation:

1. The justification principle,
2. The optimization principle and
3. Dose limitation. (Radiation Act 859/2018, 2nd chapter, 5§, 6§ and 7§).

Justification principle means that the result of using radiation must be a net benefit. This can mean the production of clean energy or a medical procedure of giving radiation therapy to cancer cells. The optimization principle means that all radiation exposures must be kept as low as reasonably achievable (ALARA-principle), taking all social and economic factors into account. Dose limitation means that individuals cannot take doses exceeding the limits set by the ICRP (International Commission on Radiological Protection) at work. The limit is 20mSv per year, or an average of 100mSv per year over five years if certain extra criteria are met. Most power plants have their own, lower

occupational limits, with 10mSv per year being widely used. (International Commission on Radiological Protection, 2007, page 98).

6 MEASURING CONTAMINATION

The undesired build-up of radioactive nuclides, or contamination, can attach themselves to any particles bound in surfaces, liquids or gases. A contaminated surface can be measured via a direct contamination measurement that detects both fixed and loose contamination, or it can be measured with an indirect measurement that only detects the loose part of the contamination. (International Atomic Energy Agency, 2024, page 9). Contamination in liquids must typically be determined in a laboratory, usually with a scintillation counter, where the radiation from the active particles is converted into light, which is then measured via photomultiplier tube. Usually, the result is given in Bq/l. Air contamination is usually determined by filtering air and measuring the radioactivity buildup of the filter. When the volume of air that passed the filter is know, a value of Bq/m^3 can be assigned to the sample.

An indirect contamination measurement is performed by wiping the surface being examined with a smear sample. This smear sample will be analyzed by an appropriate radiation measuring instrument, such as the NT200 smear test instrument with a proportional detector. To get accurate readings, a set of variables must be determined. These include the radionuclide-specific detection efficiency of the detector, geometric efficiency of the measurement, the area of the surface being wiped, and the efficiency of the removal of contamination from the surface, i.e. removal factor. In this study, the NT200 is used for obtaining the necessary data for the assessment of smear test removal efficiencies.

The NT200 has a sealed proportional detector that detects alpha- and beta radiation and can distinguish between them. It has a low sensitivity for gamma

radiation and 50mm of lead surrounding the detector enclosure - so it can be used in areas with elevated background radiation. It also has a separate background detector to reduce background radiation interference with the measurement. The unit has two trays that can be pushed in to the instrument by turn, eliminating the need for buttons in the basic operation of the instrument, and speeding up the physical measurement process of several samples and improving contamination control procedures. (Nutronic AB, 2023, page 8).

The proportional counter has an anode and a cathode, and an operational voltage between 1000V and 1500V. The detector is filled with an inert gas (Argon). This filler gas is ionized by the radiation from the samples. The quench gas (CO2) ensures the termination of each pulse discharge. The radiation from the sample ionizes the filler gas, forming ion pairs. The positive ions will gravitate to the electrode with the negative charge, and the electrons (negative charge) will move toward the central wire (positive charge). Closer to the anode the electrical field will be strong enough to cause Townsend avalanches. This is a phenomenon where the electric field accelerates electrons, which in turn free more electrons. The resulting multiplication allows an increased conduction in the gas. The resulting electric pulses are then identifed and converted into Becquerel-values by a known calibration factor. (University of Washington, 2008, page 1).

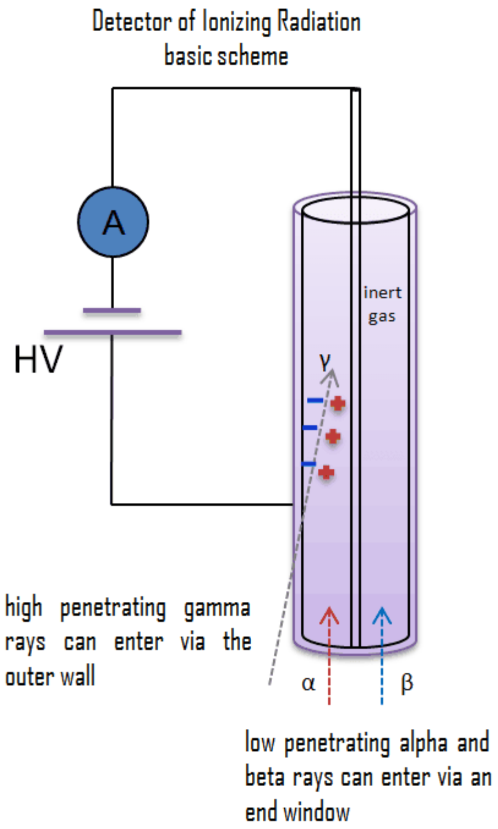

Figure 7. Basic scheme of a proportional counter ionizing radiation detector. (Nuclear-power.com, 2024).

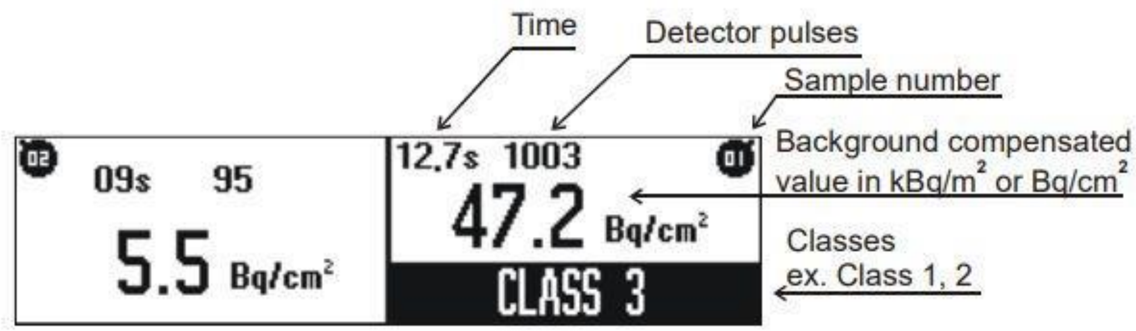

Figure 8. The instrument display during the measurement of the left cup. The right side cup measurement has been finished. (Nutronic AB, 2023, page 9).

The screen display above shows the completed measurement results on the right. It measured 1003 pulses in the course of 12,7 seconds, or approximately 79 pulses per second, which was converted to 47,2Bq/cm^2. If there is alpha radioactivity present in the sample, the instrument will sense it during the beta

measurement and trigger a subsequent alpha measurement, which will be displayed separately.

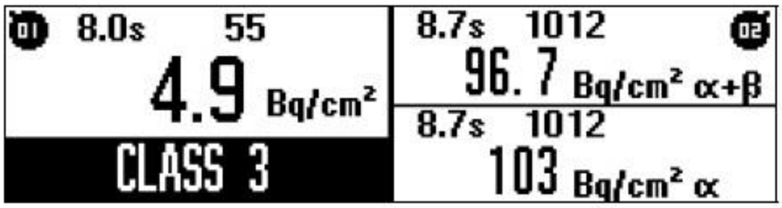

Figure 9. The right side measurement has found alpha radiation and will conduct another measurement on the lower part of the screen to display a value for the alpha portion of the activity. (Nutronic AB, 2023, page 10).

NT200 calculates the surface activity As [Bq/cm^2] with the following equation:

$$A_S = \frac{\eta - \eta B}{\varepsilon i \times \varepsilon r \times \varepsilon s \times S}$$

,where

η= measured count rate [s^{-1}]

η_B= background count rate [s^{-1}]

ε_i = detector efficiency for the radionuclide being investigated

εr= removal efficiency

ε_S = efficiency of the contamination source

S= surface area being examined [cm$^{2]}$

(Monto, 2020, page 1).

7 MEASUREMENTS

5.1 Data acquirement

The measurements were conducted in the outage of Forsmark Nuclear Power Plant Unit 2 decontamination room in October 2023, and the Olkiluoto Nuclear Power Plant unit 1 decontamination room and active workshop in 2023.

The removal factor was calculated by taking and measuring standard smear samples until there was no more net activity in the samples. The activity in the initial sample was compared to the sum of activities of all samples of the same surface. This ratio is the removal factor. The activity is marked in Bq/cm^2 and in pulses of radiactive decay [counts per second, or pulses]. The activity in Becquerel is shown because it is more widely used in radiation protection measurements, but the actual calculations are done with the raw pulse numbers from which the Becquerel values are derived from. The measuring time was set to 20 seconds.

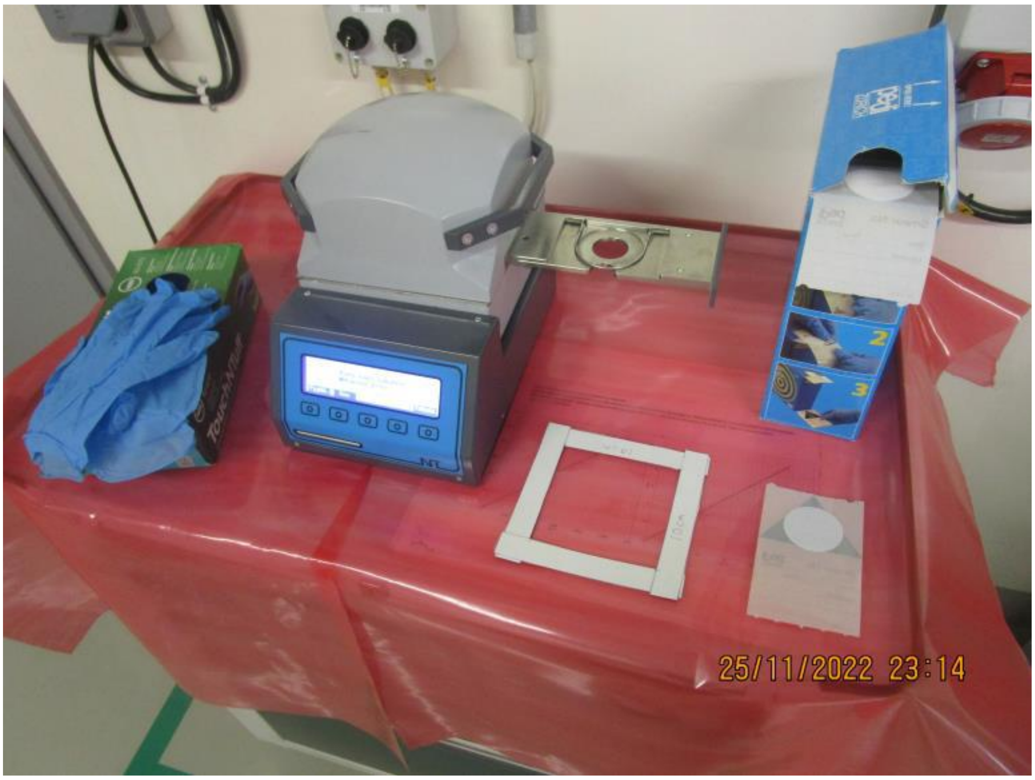

Figure 10. The equipment needed to gather the samples for this thesis: the NT200 sample reader, a stensil for 10x10cm^2 samples, smear sample papers and rubber gloves for contamination control. (Tirronen, 2023)

The removal factor is the most affected by individual actions out of all the parameters read by the NT200. Often the area wiped is not exactly 100cm^2, and people press the sample papers to the surface with different pressure. In this thesis, we used tape to mask off an area of 10cm by 10cm to ensure correct sampling area, and we used three different people to take the samples to account for individual differences in the pressure used in sample taking.

Figure 11. An area of 10cm x 10cm taped to a painted concrete floor inside the decontamination room of Olkiluoto unit 1. The surface has been exhausted of dirt and contamination. (Tirronen, 2023).

Figure 12. The previous test surface after the masking has been removed. It is important the tape sits tighly so only the $100cm_2$ area is being swiped. (Tirronen, 2023).

8 RESULTS

A polymeric plug of a plugging machine, some conventional dirt on the surface:

Sample	Activity[Bq/cm²]	Pulses/20s	Sample	Activity[Bq/cm²]	Pulses/20s
1	7,1	260	14	0,55	32
2	5,8	214	15	2,1	83
3	3,8	148	16	1,2	49
4	3,2	126	17	0,34	22
5	4,7	179	18	0,39	19
6	3,6	132	19	0,82	36
7	1,5	61	20	1,6	62
8	6,6	244	21	0,89	36
9	1,9	75	22	0,93	39
10	1,0	43	23	0,81	35
11	1,7	65	24	0,47	21
12	1,3	51	Tot.	53,60	2123
13	0,58		1/Tot.	0,132	0,122

Defining the background activity for the NT200-instrument with unused smear:

Sample	Activity[Bq/cm²]	Pulses/20s
1	0,36	17
2	0,48	27
3	0,52	27
4	0,22	21
5	0,28	15
6	0,72	30
7	0,34	17
8	0,37	23
9	0,36	17
10	0,80	31
AV	0,445	22,5

The bottom of a plastic tool box. Even and clean surface:

Sample	Activity[Bq/cm²]	Pulses/20s	Sample	Activity[Bq/cm²]	Pulses/20s
1	5,7	210	10	0,5	21
2	0,62	29	11	0,56	25
3	2,2	82	12	0,19	15
4	0,34	21	13	0,75	36
5	0,71	31	14	0,43	21
6	0,26	15	15	0,43	21
7	0,47	24	Tot.	14,22	601
8	0,4	20	1/Tot.	0,401	0,349
9	0,66	30			

Defining the background activity for the NT200-instrument with unused smear:

Sample	Activity[Bq/cm²]	Pulses/20s
1	0,62	24
2	0,76	33
3	0,49	25
4	0,63	30
5	0,26	15
6	0,74	33
7	0,51	21
8	0,64	32
9	0,26	15
10	0,52	23
AV	0,543	25,1

Painted concrete floor, with visible conventional dirt:

Sample	Activity[Bq/cm²]	Pulses/20s	Sample	Activity[Bq/cm²]	Pulses/20s
1	22,3	695	11	0,76	24
2	5,5	173	12	0,76	25
3	1,7	52	13	0,87	27
4	1,4	43	14	0,76	24
5	1,4	44	15	0,76	24
6	1,2	37	16	1,00	32
7	1,5	47	17	0,67	21
8	1,1	34	Tot.	43,52	1358
9	0,87	27	1./Tot.	0,512	0,512
10	0,93	24			

Defining the background activity for the NT200-instrument with unused smear:

Sample	Activity[Bq/cm²]	Pulses/20s
1	0,42	13
2	0,64	20
3	1,00	32
4	0,64	20
5	0,87	27
6	0,80	25
7	0,76	24
8	0,71	22
9	1,10	33
10	0,80	25
AV	0,774	24,1

Steel drain pool:

Sample	Activity[Bq/cm²]	Pulses/20s	Sample	Activity[Bq/cm²]	Pulses/20s
1	32,3	1171	10	0,47	24
2	18,6	672	11	0,33	20
3	2,0	77	12	0,52	26
4	0,75	34	13	0,24	11
5	0,48	27	14	0,86	38
6	0,70	34	15	0,44	20
7	0,42	21	Tot.	59,1	2223
8	0,56	26	1/Tot.	0,547	0,527
9	0,43	22			

Defining the background activity for the NT200-instrument with unused smear:

Sample	Activity[Bq/cm²]	Pulses/20s
1	0,17	12
2	0,46	23
3	0,22	13
4	0,62	28
5	0,34	18
6	0,63	30
7	0,51	20
8	0,42	20
9	0,51	20
10	0,87	29
AV	0,475	21,3

Stainless steel door, flat and clean surface:

Sample	Activity[Bq/cm²]	Pulses/20s	Sample	Activity[Bq/cm²]	Pulses/20s
1	1823	3002	10	3	10
2	65	112	11	5	11
3	28	51	12	3	8
4	12	23	13	7	13
5	14	25	14	1	7
6	8	20	15	3	8
7	3	9	Tot.	1989	3328
8	7	15	1/Tot.	0,917	0,902
9	7	14			

Bagkround before measurement: 4Bq/cm^2, 8 detector pulses.

Background after measurement: -1Bq/cm^2, 4 detector pulses.

Epoxy floor surface, slightly scratched:

Sample	Activity[Bq/cm²]	Pulses/20s	Sample	Activity[Bq/cm²]	Pulses/20s
1	667	1099	20	6	16
2	458	764	21	5	16
3	105	178	22	25	44
4	167	283	23	11	25
5	35	61	24	6	14
6	27	48	25	6	11
7	14	31	26	16	27
8	18	32	27	2	11
9	10	19	28	1	7
10	27	51	29	5	12
11	6	15	30	4	11
12	9	17	31	0	6
13	2	13	32	2	6
14	7	16	33	3	9
15	10	22	34	6	13
16	14	30	35	4	13
17	6	13	Tot.	1700	2969
18	7	17	1/Tot.	0,392	0,370
19	9	19			

Bagkround before measurement: 8Bq/cm^2, 1 detector pulses.

Background after measurement: 4Bq/cm^2, 2 detector pulses.

The small difference in the ratios between the pulses and the activities is caused by the rounding error, which cumulates when measuring multiple samples.

9 CONCLUSIONS

The results for the removal factors measured for the examined surfaces are as follows:

Polymeric plug	12.2%
Plastic tool box	34.9%
Painted concrete floor	51.2%
Steel drain pool	52.7%
Stainless steel door	90.2%
Epoxy floor	37.0%

The lowest amount of activity was collected by the smear sample with the most porous material, the polymeric plastic plug. The removal factor in this case was only 12.2%.

This data indicates that the traditional value of 10% for the removal factor to be used in the NT200 analyzer calculations would be a good, conservative value that leaves a safe margin of error for indirect contamination measurements.

The data produced in this thesis was not sufficient to yield a significant research result. Further research is needed for this topic.

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