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MONITORING OF RADIOACTIVE RELEASES AT LOVIISA NPP: PROCESS DESCRIPTIONS AND RECOMMENDATIONS

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Examiners: Professor, D.Sc. (Tech) Tuomas Koiranen
Master of Science (Tech) Timo Kontio

ABSTRACT

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Monitoring of Radioactive Releases at Loviisa NPP:
Process Descriptions and Recommendations

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The aim of this thesis is to prepare process descriptions describing the main discharge processes and to identify the weaknesses in these processes and give recommendations in order to prevent further operational events. The process descriptions are based on the several process descriptions, PI-diagrams, and instructions available. In addition, all reports from previous operational events were studied and several people were interviewed.

The main finding was that the events related to discharge processes have mainly been caused by so-called human error. Whereas in the nuclear industry the rule based errors are generally the most presented group, in Loviisa NPP over half of the events related to discharge processes were skill based, rule based errors being almost nonexistent. The Loviisa NPP has an existing event reporting culture, which should be utilized more efficiently and more attention need to be paid on following the effects of the implemented actions.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
LUT School of Engineering Science
Master's Program in Chemical and Process Engineering

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Radioaktiivisten päästöjen tarkkailu ja raportointi Loviisan voimalaitoksella: prosessikuvaukset ja kehitysehdotukset

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DI Timo Kontio

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Tämän diplomityön tarkoitus on laatia prosessikuvaukset Loviisan voimalaitoksen tärkeimmille päästöprosesseille, sekä tunnistaa prosesseihin mahdollisesti liittyviä heikkouksia sekä esittää korjausehdotuksia. Prosessikuvaukset pohjautuvat useisiin yksittäisiin prosessikuvauksiin, PI-kaavioihin, sekä ohjeistuksiin. Lisäksi työssä hyödynnettiin menneitä tapahtumaraportteja sekä haastatteluja.

Päästöprosesseihin liittyvät tapahtumat johtuivat pääosin inhimillisestä virheestä, ja virhetyyppijakauma erosi ydinvoimateollisuudessa yleisesti havaittavasta jakaumasta. Loviisan voimalaitoksella on hyvä olemassa oleva raportointijärjestelmä, jota tulisi jatkossa hyödyntää paremmin, jotta samankaltaisten tapahtumien toistumiselta vältyttäisiin.

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LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
FSAR	Final Safety Analysis Report
EURATOM	European Atomic Energy Community
IAEA	International Atomic Energy Agency
IPPA	Interactive Pre-Processing Apex (Part of the Apex Family of Productive Software by Canberra)
LaMDA	LIMS used at Loviisa NPP
LIMS	Laboratory Information Management System
NPP	Nuclear Power Plant
OLC	the Operational Limits and Conditions
ST	Regulatory Guides on radiation safety
STUK	the Finnish Radiation and Nuclear Safety Authority
YVL	Regulatory Guides on nuclear safety

1 INTRODUCTION

The use of nuclear power always presents a potential risk to the environment, human health and the economy. To keep this risk at its minimum, nuclear industry operates under strict regulations. Over the past few years, there have been a couple of operational events at Loviisa NPP related to the monitoring and reporting of radioactive releases. This has raised awareness that in order to prevent further events, the operations connected to this monitoring should be scrutinized and corrective actions implemented.

1.1 Background

All facilities that may release radionuclides into the environment must have a monitoring plan in order to detect and measure these releases. In addition, ionizing radiation being a well-known carcinogen, the potential impacts of the releases on public needs to be evaluated. In Finland, the radioactive releases are regulated – as well as all nuclear operation – according to Nuclear Energy Act (990/1987). The Finnish Radiation and Nuclear Safety Authority, STUK, supervise the application of this act. In addition, STUK is authorized to specify detailed safety requirements. These detailed requirements, including the release limits for radioactive releases, are described in regulatory guides. There are two sets of the regulatory guides: Regulatory Guides on nuclear safety (YVL Guides) and Regulatory Guides on radiation safety (ST Guides). In addition, instructions to rescue professionals in case of radiation emergency situations are given in VAL Guides.

Throughout the operation history of the Loviisa NPP, the annual radiation dose from Loviisa NPP to the most exposed person of the public has been very low (see Figure 1). However, there has been an increased number of operational events in the Loviisa NPP concerning the monitoring of the releases. This indicates that some corrective actions are needed in order to prevent further events. As stated in YVL Guide A.10 (2013):

According to Section 24 of Government Decree 717/2013, operating experience feedback and safety research results shall be monitored and assessed in order to enhance safety. Safety-significant operational events shall be investigated for the purpose of identifying the immediate and underlying causes as well as defining and implementing the corrective and preventive actions.

In this case, ensuring the correct and accurate release monitoring is considered as a safety-significant operation, because incorrect detecting and measuring of the releases leads to incorrect reports and incorrect calculated radiation doses. Hence, the radiation exposure can be – in the worst case – underestimated.

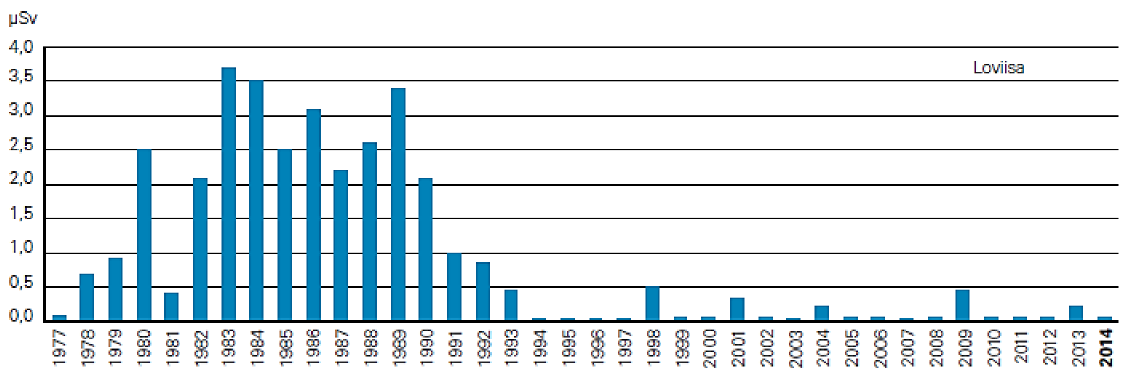

Figure 1 Annual radiation doses to the most exposed person of the public since the start of operation of the Loviisa nuclear power plant. The doses are calculated based on the recognized radioactive releases. Over the recent years, the doses have remained below one percent of the set limit, 0.1 mSv/a (Kainulainen, 2015)

The monitoring of the releases is a complex process that includes work input of several different organization units. The operating experiences have shown that for example communication problems between different units can lead to further problems within laboratory analysis and release reporting.

1.2 Research Objectives

The objective of this study is to prepare process descriptions describing the main discharge processes and to identify the weaknesses in these processes and give recommendations in order to prevent further operational events. The power plant has studied every operational event as stated in YVL Guide A.10 (2013) and proposed and implemented corrective actions. This should prevent similar events from reoccurring. The goal of this study is to identify possible weaknesses in the existing processes and provide recommendations. In addition, having the visual process descriptions may make it easier for the persons who are working with the release processes to see the big picture and to perceive the meaning of their work in a larger scale.

The investigated release processes were narrowed down to the three main release routes of the primary side: ventilation stack, control tanks and special sewerage system of the laboratory building. Examples of the study targets are presented in Table I in a form of short questions.

The complete process descriptions should make the relations between the operations clearer. These process descriptions could be used as a training tool, when organizing advanced training for the employees. The employees' better knowledge about these relations should prevent misunderstandings and problems based on the lack of communication and knowledge. In addition, the identification of potential problems while preparing the process descriptions is an important way to enhance process safety and reliability.

Table I Examples of questions that need to be answered during the preparation of process descriptions.

Human actions	Process equipment
Sampling: How are the laboratory samples taken? Are the samples representative?	Sampling: How does the sample flow to the instrument happen? Is the sample representative?
Maintenance: Is the maintenance sufficient? Are the maintenance tasks shared effectively between organizations?	Measurements: Are the results correct? How are the results evaluated? What actions are taken to ensure correct results?
Inspections: Are the inspections sufficient? Are the possible risks spotted in time?	Operational limits: Are the operational limits correct? What happens if the limits are exceeded?
Knowledge transfer: Is the knowledge transfer between organizations and individuals sufficient?	Alarms: What are the alarm limits? How are the alarms tested?
Instructions and training: Are all actions instructed properly and are the instructions kept up to date? Is sufficient training arranged in all areas?	Maintenance: Is the maintenance sufficient? Do the instruments have self-diagnostics?
Monitoring: Who monitors the results (both laboratory results and instrument results)? How are deviations spotted and handled?	

1.3 Research Methods

The first step in the research was the preparation of the process descriptions for each release route. The process descriptions are based on the several process descriptions, PI-diagrams, and instructions available. In addition, all reports from previous operational events were studied and several people were interviewed.

1.4 Thesis Outline

The thesis is divided into eight chapters. The second chapter explains the monitoring of radioactive releases in a general level, emphasis being on Finnish regulations and demands, and following questions are answered: Why are the radioactive releases monitored in the described level? What kind of legislation and regulations are attached to the release monitoring? What are these releases and how are they measured and reported? How is the reliability of the results guaranteed?

The preparation process of the process descriptions is shortly described in the third chapter. The fourth chapter explains the methods used to detect the possible problems. Also potential problem areas that arose from the study of the past operational events are discussed and a small literature study concerning the problem areas is made.

The obtained process descriptions are described in the fifth chapter. In the sixth chapter, the detected problems are described and recommendations are given in the seventh chapter. The eighth chapter consists of conclusions.

2 RADIOACTIVE RELEASES FROM A NUCLEAR POWER PLANT

In this chapter, the monitored releases and the main release paths in Loviisa NPP are introduced. In addition, the regulations related to the monitoring of radioactive releases from a nuclear power plant in Finland are described in general.

2.1 Radioactive Releases

There are three main artificial sources of radionuclides found in the environment: Fallout from the atmospheric nuclear bomb tests, routine releases from nuclear reprocessing plants and nuclear power plants and accidents at nuclear facilities, the most significant being the Chernobyl accident (Maeda, et al., 2011). As atmospheric bomb tests are prohibited nowadays, the only controlled releases are from reprocessing plants and nuclear power plants.

Normal operation of nuclear power plants generates a large inventory of radioactive nuclides. Some of these radioactive nuclides are able to migrate to the release routes. The release routes contain different kinds of cleaning processes that reduce the amount of radioactive substances entering the environment. In addition, the routes are also designed to delay the release, so the number of nuclides with a short half-life are minimized in the release. Nevertheless, small amounts of radioactive substances are released into the environment during normal operation of a nuclear power plant.

Radioactive releases from the Loviisa NPP to the environment have been very low during recent years. Releases from years 2012 and 2013 accompanied with the release limits, are presented in Table II and Table III.

Table II Forms of radioactive releases to sea in Loviisa NPP in year 2012 and 2013. Annual release limit is presented as reference (Fortum Loviisan Voimalaitos, 2015).

Released nuclides	Year 2013, TBq	Year 2012, TBq	Release limit, TBq/a
Tritium	15.9	15.1	150
Other radioactive nuclides	0.00119	0.000306	0.89

Table III Forms of radioactive releases to air in Loviisa NPP in year 2012 and 2013. Annual release limit is presented as reference (Fortum Loviisan Voimalaitos, 2015).

Released nuclides	Year 2013, TBq	Year 2012, TBq	Release limit, TBq/a
Noble gases as Kr-87ekv	6.5	5.56	14 000
Iodine as I-131ekv	0.0000249	0.000000225	0.22

2.1.1 Generation of Radionuclides

At the very beginning of the operation of a nuclear power plant, the only radionuclides present are the uranium isotopes in the fresh nuclear fuel. During the operation, fission products are generated inside the fuel rods. In addition, activation products are generated in the neutron field of the reactor. (Neeb, 1997; Riess, et al., 2010).

As the name suggests, fission products are generated in a nuclear fission, in which a large nucleus splits into smaller ones, releasing neutrons and energy mostly in the form of kinetic energy of the particles. One example of the nuclear fission of uranium-235 is presented in Figure 2.

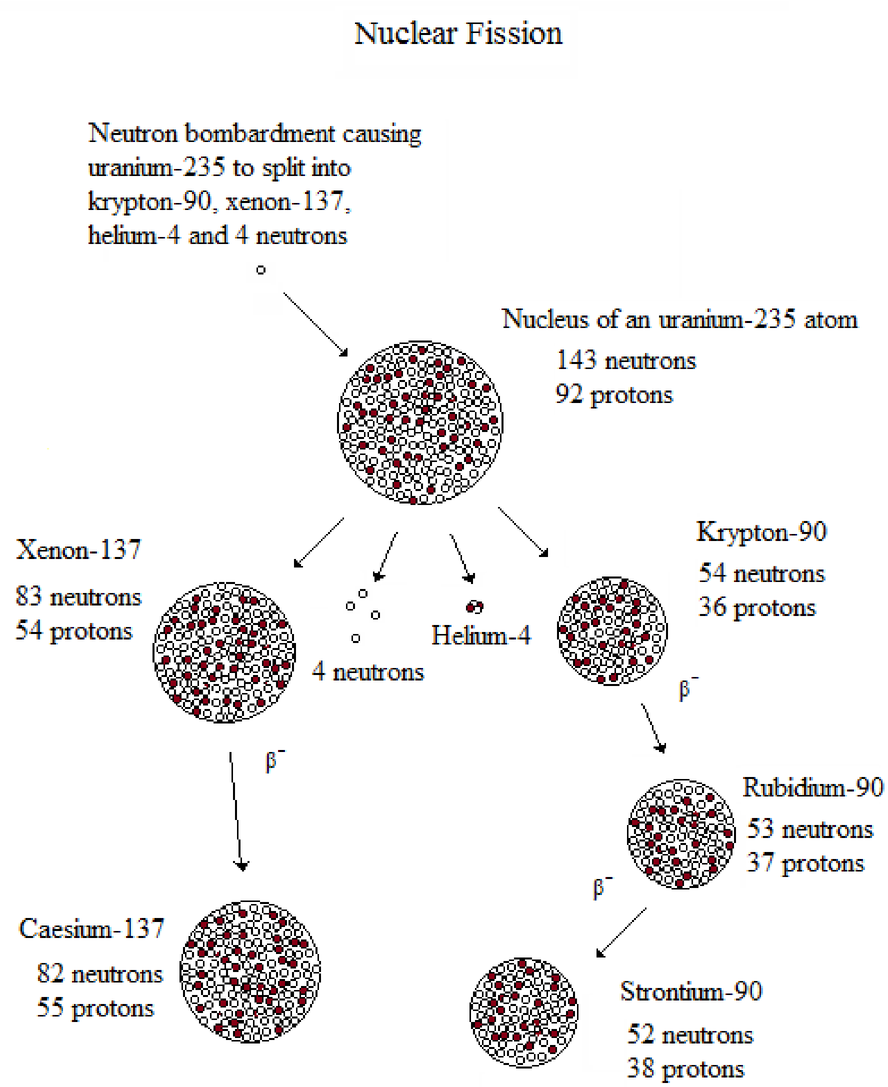

Figure 2 Nuclear fission of uranium-235 caused by neutron bombardment. Xe-137, Kr-90, and Rb-90 are short-lived fission products with half-lives of less than five minutes. Cs-137 and Sr-90 are more stable with half-lives of about 30 years and therefore possess a long-term radioactivity hazard to the environment.

Fission is rarely symmetrical and the mass numbers of the fission products alter. Yields of fission product chains for the thermal-neutron fission of U-235 and Pu-239 are presented in Figure 3. The maximum fission product yields of U-235 occur around mass numbers A = 95 and A = 138. Fission products usually have excess neutrons and therefore most of them decay via β^- -decay towards stable isotopes. (Riess, et al., 2010).

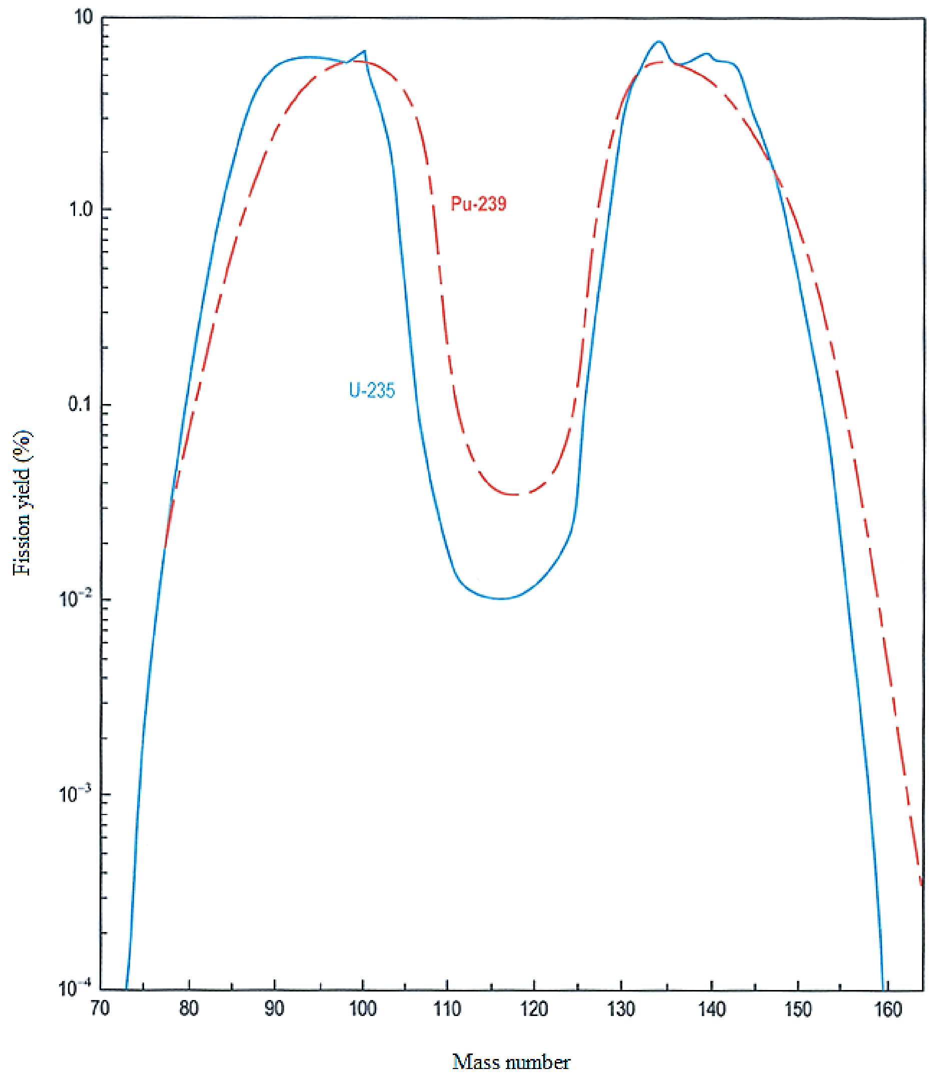

Figure 3 Yields of fission product chains for the thermal-neutron fission of U-235 and Pu-239 (Riess, Rühle, & Odar, 2010).

Activation products can be divided into two groups: 1) water and activation products of additives and impurities and 2) activated corrosion products (Riess, et al., 2010). Water flowing through the core region of a nuclear power plant contains different chemicals, impurities and corrosion products. As the water enters the neutron flux zone, the neutron bombardment can activate otherwise stable nuclides via neutron capture. Radioactive nuclides generated this way are called activation products. (Riess, et al., 2010). Activation of corrosion product cobalt-59 is presented in Figure 4. Activation is also possible inside the fuel rods, where fission products can capture neutrons (Neeb, 1997) and in the neutron flux outside the reactor core, for example nuclides in the pressure vessel, in the concrete materials and in the air, can capture neutrons. For example, the stable argon-40 in the air can be activated into radioactive argon-41 (Rantamäki, 2007).

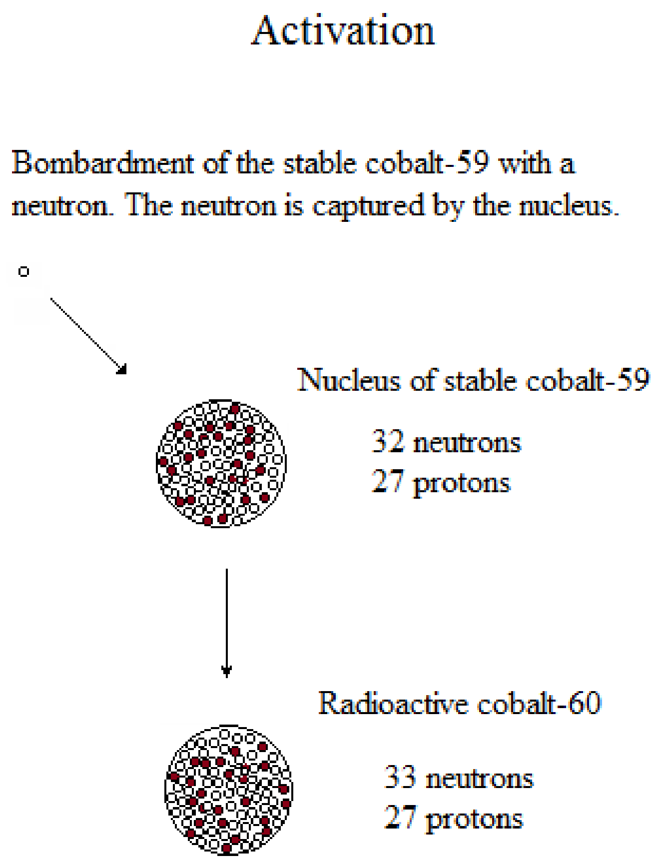

Figure 4 Neutron capture by stable cobalt-59 forms a radioactive nuclide cobalt-60 with a half-life of 5.27 y.

Some important nuclides in terms of radiation protection and their ways of generation are summarized in Table IV.

Table IV Summary of some important nuclides in terms of radiation protection. Information from The Lund/LBNL Nuclear Data Search, http://nucleardata.nuclear.lu.se/toi/nucSearch.asp (Chu, Ekström, & Firestone, 1999).

Nuclide	Half-life	Generation type	Radiation type
H-3	12.3 a	Activation product	β^-
		Fission product	
C-14	5730 a	Activation product	β^-
Ar-41	1.83 h	Activation product	γ
Co-60	5.27 a	Activated corrosion product	γ
Sr-90	28.5 a	Fission product	β^-
I-131	8.02 d	Fission product	γ
Cs-137	30.17 a	Fission product	γ

2.1.2 Migration of Radionuclides

The fission products accumulate inside the gas-tight, sealed fuel rods during operation. Therefore, fission products do not appear in significant amounts in other areas of the power plant. The accumulation of fission products, however, changes the chemical composition of the fuel and according to Neeb (1997), it is suggested that some of the fission products may act as an initiator to the weakening of the fuel rod cladding.

The fission products are released from the fuel rod in case of a fuel rod failure. Main failure causes in PWRs are grid to rod fretting, debris related failures and fabrication related failures (IAEA Nuclear Energy Series, 2010). When the fuel rod is damaged, fission products can leave the rod and enter the primary coolant, leading to primary circuit contamination. The nature of the contamination depends on the nature of the rod failure; in very small failures, only nuclides in gas form are able to leave the rod, whereas in case of a bigger failure, the variety of released nuclides is wider and the released amounts are bigger.

Fuel rod failures are rare events, especially when compared to the total amount of fuel rods in the core. As stated in Regulatory oversight of nuclear safety in Finland, Annual report 2014 (Kainulainen, 2015), there have been very few leaking fuel rods in the Finnish nuclear power plants and the leaks have been small. This is due to the high quality of the used fuel and stable operation and water chemistry of the power plants.

Some fission products are always present in the primary coolant. This is due to the contamination of the primary circuit from the previous fuel rod failures and uranium traces on the outer surface of the fresh fuel rods, originating from the fabrication procedures. In addition, tritium can slowly penetrate the fuel rod cladding via diffusion (Neeb, 1997). The primary coolant contains also a variety of different activation products.

Discharge to the water environment are mainly due to the deborating and borating processes of the primary coolant and cleaning of the drain water. Waters are released to the sea after cleaning processes. These processes are described in detail in Chapter 5.2 Control tanks TD/TR. The most important nuclide in the liquid effluents is tritium. (Rantamäki, 2007).

Discharge to the atmosphere are mainly due to the cleaning processes of the process gases and primary coolant, and due to the normal ventilation of the power plant. The air of the reactor building contains small amounts of radioactivity due to the leakages of the primary coolant, sample drainings and the activation of the air. Likewise, the air of the turbine building can have radioactivity due to the leakages of the secondary coolant, which can be contaminated due to the leakage from the primary circuit. In addition, very small amounts of radioactivity are present in the air of the laboratory building, as radioactive samples of the primary coolant are handled daily in the laboratory. The most important nuclides in the exhaust air are tritium, carbon-14, and argon-41. (Rantamäki, 2007).

The possible migration routes of the radionuclides from the power plant to a human being are described in Figure 5. The current system of radiation protection focuses to protect humans from the effects of ionizing radiation. Therefore, the radiation dose to humans is strictly controlled and actions are made to reduce it even further. The traditional concept of environmental radiation protection believes that actions needed to protect humans will ensure that also other species of the environment are protected. (Maeda, et al., 2011).

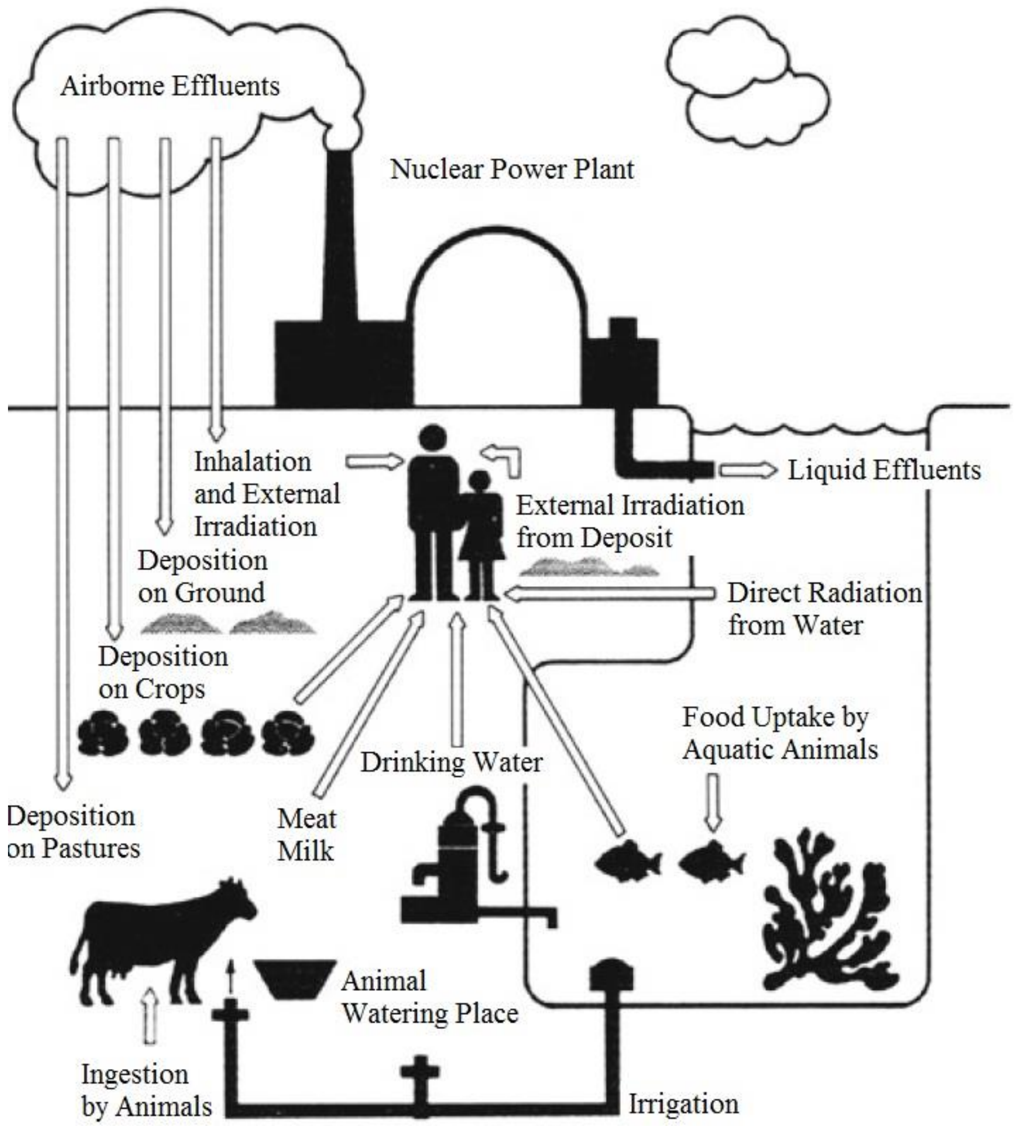

Figure 5 Possible radiation exposure pathways to man from the nuclear power plant (Kessler, 1983).

The chemical properties of the released substances play an important role in the transport and biochemical cycling of the nuclides in the environment. For example, the released noble gases are not considered biological material as they do not bind to organic matter. Most important monitored nuclides are ^{3}H, ^{14}C, ^{90}Sr, ^{131}I, and ^{137}Cs. (Maeda, et al., 2011). These nuclides are described in detail in following paragraphs.

2.1.3 Tritium

Tritium, ^{3}H, is a naturally occurring radioisotope of hydrogen, which is created in the upper atmosphere by the interaction of cosmic rays with nitrogen or oxygen nuclei. (Momoshima, et al., 2007). Tritium is very mobile and is therefore incorporated in biological substances. (Maeda, et al., 2011).

In the Loviisa NPP, most of the released tritium is generated in the primary coolant from the dissolved boron with a reaction $^{10}B(n,2\alpha)^{3}H$. Tritium has a relatively long half-life (12.3 a) and delaying the release in order to reduce the amount of released tritium is not reasonably achievable. Therefore, the amount of the release is directly proportional to the generation of tritium. Tritium is discharged mostly to the sea in the form of tritiated water (HTO), but a part of the release is discharged to the atmosphere. (Rantamäki, 2007).

HTO is bound to the plants and animals in the similar manner as normal water, and the HTO/H_2O ratio in living matter is close to the existing ratio in the environment. As tritium is a β-emitter, the radiation exposure to human is caused by the internal tritium, organically bound to the tissues, which enters the body in the form of food and drinking water. Some tritiated water can also be absorbed by inhalation or through the skin. (Kessler, 2012).

2.1.4 Carbon-14

Carbon-14 is a naturally occurring isotope of carbon, which is – similarly to tritium – produced in the upper atmosphere by interaction of the cosmic rays with nitrogen or oxygen nuclei. ^{14}C is very mobile and bound to organic matter similarly to normal carbon. The half-life of carbon-14 is very long (5730 a) and the ^{14}C concentration in living matter is in equilibrium with the ^{14}C concentration in the environment. The specific activity of the ^{14}C in living matter is estimated to be 0.28 ± 0.10 Bq/g of carbon (Maeda, et al., 2011).

In the Loviisa NPP the carbon-14 is generated in the primary coolant mainly from ^{17}O with reaction $^{17}O(n,\alpha)^{14}C$ and in a minor way from ^{14}N with reaction $^{14}N(n, p)^{14}C$. Due to the long half-life, the releases of carbon-14 are proportional to the generation of the carbon-14. (Rantamäki, 2007). Carbon-14 can be discharged to the atmosphere as CO, CO_2, CH_4, HCHO and COS (Maeda, et al., 2011).

$^{14}CO_2$ incorporates the global carbon cycle and bounds to plants via photosynthesis. Similarly to tritium, carbon-14 is also a β-emitter and radiation exposure is mainly a result of internal carbon-14.

2.1.5 Strontium-90

Strontium-90 is a fission product that occurs in the nature due to human actions. The nuclear bomb tests, Chernobyl accident and routine discharges from nuclear facilities are responsible of the Sr-90 fallout level of today. (Maeda, et al., 2011). Strontium-90 can be released into the atmosphere as aerosols or to sea with liquid effluents. (Kessler, 2012).

Strontium is absorbed to easily available sorption sites on mineral surfaces and organic particles. Bioaccumulation of strontium follows the same mechanisms as calcium, both being group II elements. The radiotoxicity of Sr-90 is based on to its incorporation into bone tissue and relatively high β-radiation energy of 2.3 MeV of the daughter product Y-90 (half-life 2.7 d). Therefore, Sr-90 forms a long-lived radiation source (biological half-life time 18 years) placed near the blood forming organs. (Kessler, 2012).

Sr-90 traces detected in the environmental radiation monitoring near the Loviisa NPP are mostly originated from the Chernobyl accident and nuclear bomb tests. As the Sr-90 releases from the Loviisa NPP have been very small during the operation of the power plant, the increase of the environmental Sr-90 fallout due the releases from the Loviisa NPP has not been detected (Marjamäki, et al., 2015).

2.1.6 Iodine-131

Iodine-131 is a fission product with a short half-life (8.02 d). Iodine occurs in gaseous effluents as elemental iodine and as organic compounds. From air, the iodine is deposited on the surfaces of plants. It is also soluble in water and binds strongly to soils. (Smith & Beresford, 2005).

Iodine is an important nutrient for humans and many animals, as iodine is needed to produce thyroid hormones. Radioactive iodine can enter the human body by inhalation or by ingesting contaminated foodstuff. Ingested iodine is transferred to thyroid gland. Concentrated radioiodine causes high local radiation exposure, as I-131 emits both β- and γ-radiation. Incorporation of I-131 in the thyroid is decreased if dietary intake of stable iodine has been at a sufficient level. Therefore, accumulation of radioiodine in case of a nuclear accident can be prevented in some extent by potassium iodide tablets. However, this preventing feature is obtained only if the iodine supplement is digested before radioactive iodine exposure. (Smith & Beresford, 2005).

Iodine releases from the Loviisa NPP have been very small during the recent years. The discharged amount increases periodically due to scheduled tests of the activated carbon filters or during and after cases of leaking fuel rod. In these tests, radioactive iodine is injected into upstream of the ventilation system as a tracer and the performance of the filters is evaluated (Marjamäki, et al., 2015).

2.1.7 Caesium-137

Caesium-137 is a fission product that occurs in the nature due to the testing and production of nuclear weapons, routine discharges from nuclear facilities and nuclear accidents (Maeda, et al., 2011). Radioactive caesium can be released both as gaseous and liquid effluent. Releases from the Loviisa NPP have been mostly in an aqueous form (Marjamäki, et al., 2015).

Caesium is very soluble and monovalent cation Cs^+ competes for binding sites on the clay mineral lattice with K^+ and NH_4^+. Caesium does not have any known biological role in organisms. However, as chemically similar potassium – also a group I element – is an important nutrient, plants can accidentally consume caesium. Especially if the soil is low on nutrients (mainly K^+) caesium is bioaccumulated to plants. (Smith & Beresford, 2005). Radioactive caesium enters human body through the food chain and is distributed throughout the body in highly soluble compounds. (Kessler, 2012).

The amount of caesium in the releases of the Loviisa NPP has decreased notably after year 1990 (see Figure 1 in the Chapter 1.1). This is due to the start-up of caesium removal plant. In this new process, the liquid concentrates containing caesium have been treated with an ion exchanger CsTreat® that removes caesium nuclides from the liquid. (Marjamäki, et al., 2015).

2.2 Health Effects of Radiation

As mentioned in the Chapter 1.1, radioactivity is a well-known carcinogen. Radiation exposure can damage the DNA and lead to the death of cells. The DNA damage can lead to cancer. The effects caused by radiation exposure are divided to *deterministic* and *stochastic effects.*

Deterministic effects occur when a certain threshold of exposure has been exceeded. Effects are caused by cell damage or cell death and the severity of the consequences increases as the dose of radiation exposure increases. The occurrence of physical effects depends on the extent of the cell death. Some organs and tissues are more sensitive towards cell death than others. The physical effects can be for example skin erythema and epilation, cataract, permanent or temporary sterility, fetal death and acute radiation syndrome. (Goodman, 2010).

Occurrence of stochastic effects follows a linear no-threshold hypothesis, meaning that there is no clear threshold level for effects to occur, but the risk of an effect to occur increases as the dose increases. Effects are caused by damage in genetic material. This can result in cancer even years after the exposure. Even heritable diseases in the descendants of the exposed individual have been reported in animal experiments. (Goodman, 2010).

To avoid the effects caused by radiation, exposure limits are set for both the employees working with radioactivity as well as for the members of public. In addition, the use of radiation is licensed, and the licensee must follow the accepted safety practices. In Finland, these practices and exposure limits are described in Regulatory Guides on radiation safety (ST Guides).

2.3 Regulations and Guides

The nuclear regulations in Finland are based on Nuclear Energy Act (990/1987) which on the other hand is largely based on the Euratom Treaty and other international agreements. Section 7 r of the Nuclear Energy Act authorizes the Radiation and Nuclear Safety Authority (STUK) to specify detailed safety requirements. These detailed requirements are specified in two sets of regulatory guides: Regulatory Guides on nuclear safety (YVL Guides) and Regulatory Guides on radiation safety (ST Guides). In addition, in the section 55 of the Nuclear Energy Act, it is stated that STUK is responsible for the supervision of the safe use of the nuclear energy. As stated in the section 7 f, the holder of a construction or operating license is responsible for following the given regulations.

The overall plant design is provided - by the holder of the operating license - in the final safety analysis report (FSAR) which is as required in YVL Guide B.1. The limits for nuclear power plant unit operations are designed in order to enable the operating of the plant in accordance with the design bases specified in FSAR. The requirements for the operational limits and conditions (OLC) are described in detail in the YVL Guide A.6. Both FSAR and OLC must be kept up-to-date at all times. Documents must be periodically reviewed and updated to match the most recent knowledge. All changes must be approved by STUK. If the nuclear power plant is found to be at a state that is not consistent with the OLC, corrective actions must be made immediately in order to obtain compliance with OLC. All these kinds of events must be investigated and corrective actions implemented. Events must be reported to STUK as guided in YVL Guide A.10.

The safe and economic operation of a nuclear power plant requires specific instructions. The plant instructions in the Loviisa NPP are divided hierarchically in several levels. This hierarchy is visualized in Figure 6. In the highest level of plant guides is the Quality Assurance Handbook of Operation. In this handbook, the qualifications for different operations are described. On the next level are the administrative and procedure instructions, in which the procedures and responsibilities connected to the administration and other actions are described. Below these are the several different working instructions of different organizations. All the instructions are following the legislations, regulations, FSAR and OLC. (Niemi, 2006).

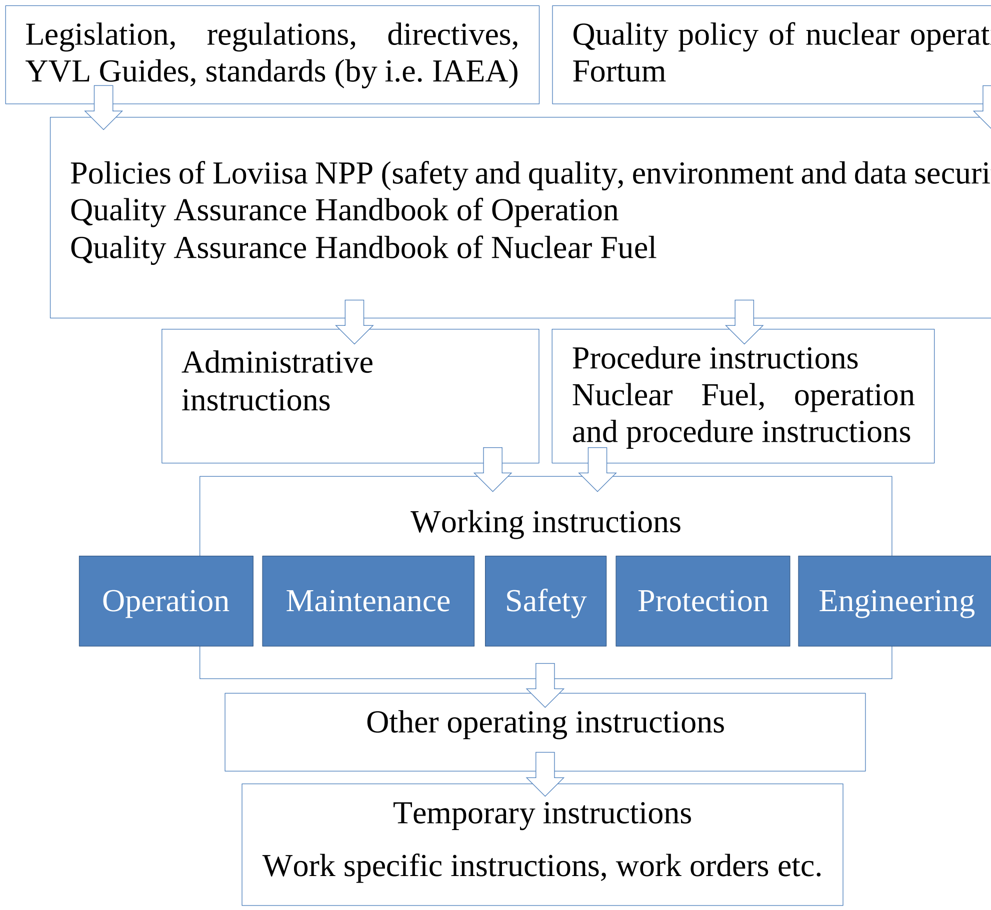

Figure 6 Hierarchical instruction system of Loviisa NPP (Niemi, 2006).

The regulations concerning the monitoring of radioactive releases from a nuclear power plant or other nuclear facility are described in YVL Guides C.3, C.4, C.6 and C.7. All regulatory guides are available on the STUK website.

2.4 Monitoring Methods

In the Loviisa NPP, the releases to the environment are continuously monitored with radioactivity monitors. The monitor readings are sent to a process computer and radiation protection supervisors follow the trend readings from the process computer daily during workweeks. More notably, the operating personnel monitors the alarms and other notifications sent by the monitors. The operating personnel receives the alarms directly to control room independently from the process computer and control room is occupied continuously. All monitors have an alarm function to alarm for activity levels exceeding the set limits. In addition, some monitors have a control function that enables automatic transfer to a release reducing process state. All monitor readings are recorded and this enables also further inspections. Monitors have self-diagnostics and can sound an alarm in a case of malfunction.

In addition, regular laboratory analyses are made from the discharges, and official discharged amounts of radioactive substances are calculated based on the nuclide based results obtained from the laboratory (Hiltunen, 2008; Kontio, 2013). The monitors and the laboratory analyses are described in detail for each release route later in the thesis.

3 PREPARATION OF PROCESS DESCRIPTION

The process descriptions described in Chapter 5 were first put together based on literature material available. Loviisa NPP has a wide collection of instructions, drawings, and different kinds of reports and education material in the plant database.

In addition, process areas were visited and some people working with the processes were interviewed. The process descriptions describing the relations between the process steps and organizational units were drawn in MS Visio.

4 PROBLEM DETECTION

In the beginning of the study, the aim was to use structured hazard identification method as HAZOP or similar. However, the existed data about past events revealed that the nature of the problems was mainly human related, and technology related problems were in minority. Although there are ways to incorporate human error analysis into process plant hazards analysis methods (Taylor, 2013), the method would have been too extensive, when taken into account the small amount and the low hazard level of the actual cases happened in the past. In fact, the studying of the past operational events, as well as the existing procedure for the corrective and preventing actions proved to be a usable method for this study.

To detect common problems associated to the release processes, the past operational events from a ten-year period were studied. This study brought up possible problem areas that were studied closer with the aid of literature to provide deeper understanding and therefore more accurate conclusions. In addition, in order to find some causes behind the human error, the employees of the laboratory of radiochemistry were interviewed by an anonymous survey.

4.1 Past Operational Events

As already mentioned in the Chapter 1.1 Background, the YVL Guide A.10 sets demand for the operating experience reporting. In Loviisa, each person working in the power plant is obliged to report all noticed faults, near misses, and other abnormalities. All reported events are discussed daily in a special meeting, and following actions are decided.

If the reported event is a disturbance or a misconduct that sets the safe operation of the power plant under a risk, the event is considered as an operational event and an operational event report is prepared. This can be the case if some part, device or system does not fill the set requirements, or the needed instructions are inadequate or non-existing, or if the existing instructions are not followed. In addition, events related to the environment and work safety, and near misses can on occasion be reported as an operational event. (Halin, 2014).

The object in the operating experience reporting is to investigate the causes and define and implement the corrective and preventing actions. The main purpose of the whole operating experience reporting is to prevent similar events from reaccuring.

For this thesis, the operational events from a ten-year period were considered. The first considered year was the year 2005, on which the total number of operational event reports was 39. On the last considered year (year 2014), the total number of operational event reports was 51. As seen in Figure 7, the total number of the event reports varies slightly annually.

The number of the events related to the discharge processes is marked in gray in Figure 7. Discharge processes are the ventilation stack (TL00), control tanks (TD/TR) and special sewerage system of the laboratory building (TZ80). It is clear that the number of these events does not correlate with the total number of the operational events. Actually, in years 2010 to 2014 there is a rising trend in the number of discharge related reports. Especially in the recent years 2013 and 2014, the amount of discharge related reports compared to the total number of all reports has been higher than ever during the period considered, being almost 10 per cent of the total number in 2014. The lack of discharge process related events during years 2005 to 2007 is also worth mentioning.

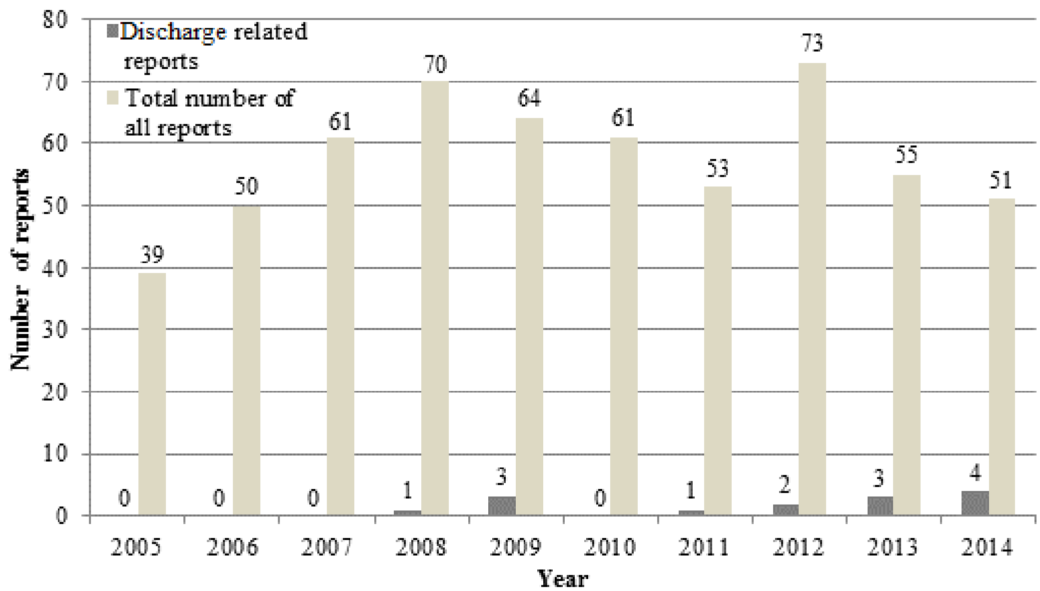

Figure 7 Annual total number of operational event reports. The event reports related to discharge processes (TL00, TZ80, TD/TR) are also presented as separate bars.

When examined closer, the events related to release processes have been mainly caused by so-called human error. Dominance of human error as a cause to the operational events is visualized in Figure 8 a. When the events are divided between the processes, as presented in Figure 8 b., it is seen that the ventilation stack (TL00) has had the most events during the considered ten-year period.

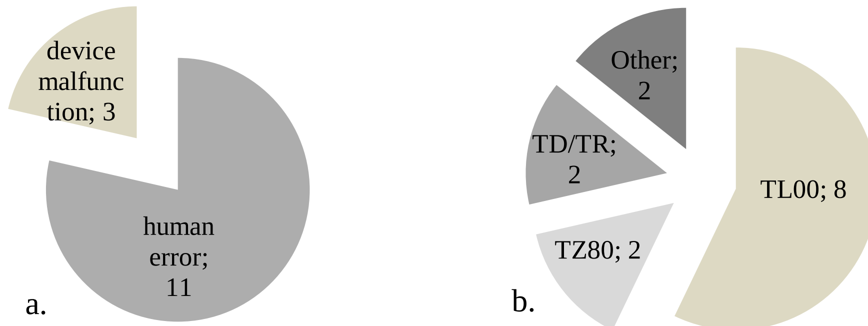

Figure 8 The event reports related to discharge processes (TL00, TZ80, TD/TR) in 2005-2014: a. causes and b. division of events between the processes. Total number of examined events was 14.

It is also worth mentioning that Jaakkola (2013) studied the operating experience reporting in Loviisa NPP as a part of his thesis. In his study he noticed that the corrective and preventing actions are not determined or/and implemented sufficiently, as there were a pattern of repeating features in the reports.

4.2 Possible problem areas

Possible problem areas were determined by investigating the past events. Three categories were chosen for closer look: sampling, human error and implementation of corrective and preventing actions.

4.2.1 Sampling

This problem area was already notified in Table I in a form of questions: are the samples representative? The parallel sampling systems in the ventilation stack (TL00) had already in the past proved that the sampling is not completely representative. Also the operational event report 17/2009 (Solja, 2009) indicated this problem.

All analytical standards and, as a result, the common laboratory practices insist that "analyses must be carried out on representative samples". The main question here is, "What is representative sample?" and this leads to question "How to obtain representable sample?"

Dr. Pierre Gy has developed a scientifically proved sampling theory, known simply as "sampling theory" or "theory of sampling (TOS)". This theory is described in his books (Gy, 1992; Gy, 1998). P. L. Smith has also released a simple introductory book on the subject, to make it more easily understandable (Smith P., 2001).

Gy (1998) states that still in industry, more attention is paid towards returning an analytical result to three or four decimal places, rather than focusing in fact that this is pointless if sampling error has every chance of being greater than the first of them. Also in official regulations focus is mainly on obtaining high precision and much less on accuracy.

Another common problem according to Gy (1998) is so called grab sampling, which according to Gy is “the art of collecting increments from the most accessible part of the batch”. Obtaining a truly representative sample is however basically impossible. The truly representative sample could be obtained when all the constituent elements of the lot have an equal probability of being taken into the sample and when the increments and the sample are not altered in any way. Basically a grab sample is the total opposite of a representative sample, as some elements of the lot have a total zero probability of being taken into the sample (Gy, 1998). The grab sampling can be considered as a correct sampling method only if the lot is perfectly homogenous.

In a nutshell, the principle of correct sampling meets following two criteria: 1) *Every part of the lot has an equal chance of being in the sample* and 2) *the integrity of the sample is preserved during and after sampling.* (Smith P., 2001). Smith (2001) presents in her book several guidelines how to obtain as representative sample as possible. Some of them are:

- Mix the material before sampling to reduce heterogeneity.
- Prefer a composite sample to reduce the impact of a poorly mixed lot.
- Increase the mass of the total physical sample to get more (randomly selected) units of the lot into the sample, and therefore to have better idea about the true lot properties.
- Use right sampling tools that follow the principle of correct sampling and use the tools correctly.

- Purge (flush) the sample line in order to get rid of the old material in the sample line.
- Collect the sample in a container made of material that will not chemically react with the sample.
- Make sure that the sample container provides proper protection to preserve the sample.
- Make sure that the used equipment is not contaminated.
- Sample frequently enough to allow for the identification of process cycles.

In order to detect possible problems in processes concerning the sampling, the sampling procedures were examined based on the presented guidelines. In addition, the standard ISO 2889 and German Safety Standards of the nuclear safety standards commission KTA 1504 (2007) and KTA 1503.1 (2013) were used as a reference material, as the Finnish authorities do not provide detailed sampling guidelines.

4.2.2 Human Error

As clearly shown in Figure 8, the dominant cause in the considered operational events was human error. The human errors are classified at Loviisa NPP into three categories: skill-based, rule-based and knowledge-based errors (Lamminen J., 2013a).

Skill-based errors usually happen when working in a known environment and with a familiar task. These errors are usually related to attentiveness which is, for some reason, disturbed. Rule-based errors are related to tasks that need implementation of rules. Either good rules are followed incorrectly, or the correctly followed rules are bad. In these cases, also unwritten rules acquired for example via training, are considered as rules. Knowledge-based errors happen when human faces an unusual situation and there are no rules available to follow. (Lamminen J., 2013b). Human error types as well as typical control measures are presented in Table V.

According to Lamminen (2013b), approximately 25 % of human error cases in nuclear industry are caused by skill-based errors, 60 % of rule-based errors and 15 % of knowledge-based errors. In the operational events considered in this thesis, the distribution of human errors was completely different. 55 % of the human error cases were caused by skill-based errors (reports 45/2014, 44/2014, 07/2014, 09/2013, 58/2009 and 51/2008) and 36 % of knowledge-based errors (reports 54/2013, 47/2013, 38/2011 and 60/2009), while the percentage of rule-based errors was only 1 % (a single report 14/2012).

Possible problems causing human errors were collected from the past operational event reports and in order to widen the scope, the personnel of the laboratory of radiochemistry were interviewed. The interviewees were the four persons who work with the release samples on a daily basis: senior laboratory technician, two laboratory technicians and laboratory analyst. The radiochemist and manager of the laboratory of the radiochemistry were left outside the survey. The interview was carried out as an anonymous survey. Each interviewee was able to self-decide the time and place for giving the answers, in order to provide the best environment for thinking the questions and answers through without any hurry.

The questions were measuring the motivation of the employees and how they experience their responsibilities as a part of monitoring processes. In addition, the questions made the employees to evaluate their own working quality and potential disturbance factors in their everyday-work. The survey also asked the employees to provide solutions for the problems they possibly had noticed.

Table V Human error types (The Health and Safety Executive (HSE), n.d.).

	Characteristics	Failure Type	Examples	Typical Control Measures
Action	Associated with familiar tasks that require little conscious attention. These 'skill-based' errors occur if attention is diverted, even momentarily. Resulting action is not intended: *'not doing what you meant to do'*. Common during maintenance and repair activities.	**Slip** (Commission)	A simple, frequently-performed physical action goes wrong: • flash headlights instead of operating windscreen wash/wipe function • move a switch up rather than down (wrong action on right object) • take reading from wrong instrument (right action on wrong object) • transpose digits during data input into a process control interface	• human-centred design (consistency e.g. up always means off; intuitive layout of controls and instrumentation; level of automation etc.) • checklists and reminders; procedures with 'place markers' (tick off each step) • independent cross-check of critical tasks (PTW) • removal of distractions and interruptions • sufficient time available to complete task • warnings and alarms to help detect errors • often made by experienced, highly-trained, well-motivated staff: additional training not valid
		Lapse (Omission)	Short-term memory lapse; omit to perform a required action: • forget to indicate at a road junction • medical implement left in patient after surgery • miss crucial step, or lose place, in a safety-critical procedure • drive road tanker off before delivery complete (hose still connected)	
Thinking	Decision-making failures; errors of judgement (involve mental processes linked to planning; info. gathering; communication etc.) Action is carried out, as planned, using conscious thought processes, but wrong course of action is taken: '*do the wrong thing believing it to be right*'	Rule-Based **Mistake**	If behaviour is based on remembered rules and procedures, mistake occurs due to mis-application of a good rule or application of a bad rule: • misjudge overtaking manoeuvre in unfamiliar, under-powered car • assume £20 fuel will last a week but fail to account for rising prices • ignore alarm in real emergency, following history of spurious alarms	• plan for all relevant 'what ifs' (procedures for upset, abnormal and emergency scenarios) • regular drills/exercises for upsets/emergencies • clear overview / mental model (clear displays; system feedback; effective shift handover etc.) • diagnostic tools and decision-making aids (flow-charts; schematics; job-aids etc.) • competence (knowledge and understanding of system; training in decision-making techniques) • organisational learning (capture and share experience of unusual events)
		Knowledge-Based **Mistake**	Individual has no rules or routines available to handle an unusual situation: resorts to first principles and experience to solve problem: • rely on out-of-date map to plan unfamiliar route • misdiagnose process upset and take inappropriate corrective action (due to lack of experience or insufficient / incorrect information etc.)	
Non-Compliance	Deliberate deviations from rules, procedures, regulations etc. Also known as 'violations' Knowingly take short cuts, or fail to follow procedures, to save time or effort. Usually well-meaning, but misguided (often exacerbated by unwitting encouragement from management for 'getting the job done').	**Routine**	Non-compliance becomes the 'norm'; general consensus that rules no longer apply; characterised by a lack of meaningful enforcement: • high proportion of motorists drive at 80mph on the motorway • PTWs routinely authorised without physical, on-plant checks	• improve risk perception; promote understanding and raise awareness of 'whys' & consequences (e.g. warnings embedded within procedures) • increase likelihood of getting caught • effective supervision • eliminate reasons to cut corners (poor job design; inconvenient requirements; unnecessary rules; unrealistic workload and targets; unrealistic procedures; adverse environmental factors) • improve attitudes / organisational culture (active workforce involvement; encourage reporting of violations; make non-compliance 'socially' unacceptable e.g. drink-driving).
		Situational	Non-compliance dictated by situation-specific factors (time pressure; workload; unsuitable tools & equipment; weather); non-compliance may be the only solution to an impossible task: • van driver has no option but to speed to complete day's deliveries	
		Exceptional	Person attempts to solve problem in highly unusual circumstances (often if something has gone wrong); takes a calculated risk in breaking rules: • after a puncture, speed excessively to ensure not late for meeting • delay ESD during emergency to prevent loss of production	

4.2.3 Implementation of Corrective and Preventing Actions

Jaakkola (2013) stated that the corrective and preventing actions in operational event reports are not determined or/and implemented sufficiently, as there were a pattern of repeating features in the reports he studied. This repertance was also present in the events considered in this study.

According to the plant instructions, the tracking of the implementation and effectiveness of the corrective actions is a part of the procedure (Halin, 2014). However, this part of the procedure has long been neglected and more detailed instructions concerning this tracking has been added to the existing instructions as late as in 2014. For the tracking of the implementation of corrective and preventing actions, there is a database called AHTI (Honkala, 2014).

The implementation of corrective and preventing actions was studied by checking how the actions described in the operational event report had been fulfilled.

5 PROCESS DESCRIPTIONS

Process description for each of the three main discharge routes of the primary side is presented in the following chapters. First route, special sewerage system of the laboratory building is located only in the plant unit 1 and is discussed in a greater detail. The control tanks TD/TR are located both in the plant unit 2 (borated water) and in the plant unit 1 (sewarage). Both systems are water treatment systems with the same operating principle. Therefore, the system is discussed in a more general level and can be implemented to both systems. Also the ventilation stack is divided between the two plant units and is therefore discussed in a general level.

5.1 Special Sewerage system of the Laboratory Building TZ80

TZ80 subsystem is a part of a special sewerage system TZ that collects sewage from the controlled area of the power plant. Clean borated water or seawater is not collected to the TZ-system.

Water in the TZ80-system is originated from the laboratory building and consists mainly of laundry water from the plant laundry, water from the hand basins and showers from the controlled area and water from the plant laboratory.

The system has two sewage tanks named TZ81B0001 or TZ82B0001. Sewage is led gravitationally via two valves either to a tank TZ81B0001 or TZ82B0001. Valves are automatic control valves that lead the sewage in either of tanks TZ81B0001 or TZ82B0001 based on the water level in the tanks. Tanks TZ81B0001 and TZ82B0001 have a volume of 20 m^3 each and each has level gauges for both upper and lower limit. Icase of maintenance in the sewerage system, the tank volumes can be combined.

Simultaneously as the valve closes down because of the signal from the tank level transmitter, the pump of the fulfilled tank starts up and discharging begins. The discharge process is shown in Figure 9.

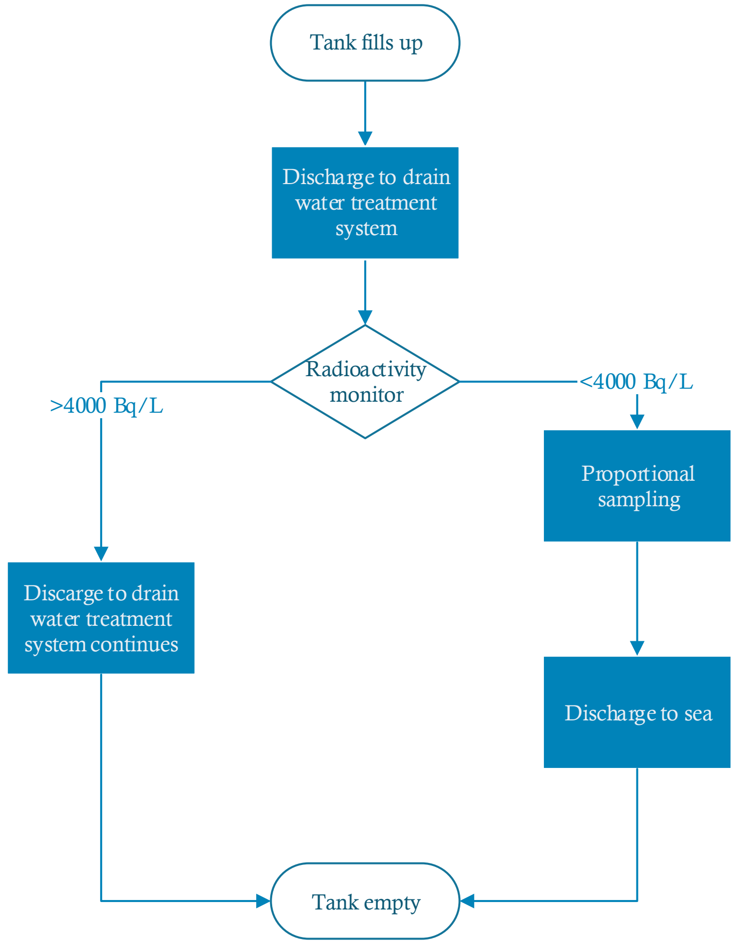

Figure 9 Discharge process of TZ80 system. Used discharge route is based on the reading of the radioactivity monitor.

The draining sewage flows through an activity meter. The activity meter sends an opening signal to the valve leading either to sea or to the water treatment system, based on the activity level of the sewage. Always in the very beginning of the discharge, the water is lead to the drain water treatment system. If the activity-level exceeds the alarm level, the whole batch is lead to the water treatment. If the activity-level of sewage is below the alarm level, after one minute of draining the sewage is led to a service cooling water system, and thus into the sea. As all radioactive discharges need to be carefully monitored and reported, a proportional sampling system is retrofitted into the system. This proportional sampling system enables representative sampling of the discharged sewage.

The proportional sampling system operates as follows: As the valve leading to the cooling water system opens the flowmeter of the sampling system starts the flow measurement and sends a start-up signal to the sampling pump which pumps approximately 0.4 liters of sewage into the sampling tank for every cubic meter of the drained sewage. As the valve closes down, the flowmeter gives a shut-down signal for the pump and the sample collection ends. The volume of the sample collection tank is 80 liters and it is equipped with a level transmitter, which gives an alarm signal if the level in the tank is reaching a too high level (approx. 70 L). The alarm signal switches on an indicator light in the corridor outside the room. The alarm signal is also triggered if the flow to the sample collection tank is too low. The indicator light signals to the operating personnel that the sample collection tank is nearly filled up and needs to be drained, or that there are problems with sample collection.

Under normal operating conditions, there is one scheduled sampling every other week. Two 1-liter samples are collected from the tank TZ81B0001 or TZ82B0001 depending on which one is currently filling. In addition, one 1-liter sample is collected from the sample collection tank. Before sampling, the content of the sample collection tank is mixed with a mixer. After sampling, the sampling tank is drained into the sewerage system and the tank is rinsed with clean water. Additional sampling is performed always if the indicator light is switched on (tank is nearly filled up). During an annual outage period, sampling is done once a week.

The samples are delivered to the plant laboratory. In the laboratory, the total gamma activity, as well as nuclide specific gamma activities, are determined from the sample from the sample collection tank. All samples are stored and a monthly composite sample is composed at the end of each month. From the monthly composite sample, tritium and total alpha activity are analyzed. From the monthly composite samples, quarterly samples are composed at the end of each quarter. From the quarterly samples Sr-89/90 is analyzed in an accredited laboratory outside the NPP. The sample taken from the tank TZ81B0001 or TZ82B0001 is analyzed to determine the total gamma activity and then sent to outside laboratory where pH, conductivity, solid concentration, total nitrogen content and total phosphorus content are analyzed.

5.1.1 Radioactivity Monitor in the TZ80-system

Radioactivity monitor in the TZ80-system is a scintillation detector with a 3" × 2" sized NaI crystal. The detector is collimated to a vertical part of the pipeline. Schematic picture of the monitor is presented in Figure 10. Both the detector and the part of the pipeline are lead shielded with five centimeters thick lead layer. The lead shielding minimizes the interfering effect of background radiation.

The monitor is checked on-site for calibration accuracy in every three months. To detect any malfunctions, the monitor device has a self-diagnostic system. The self-diagnostics of the measuring device sends an electrical test impulse periodically (every 10 minutes) to the monitor. This impulse checks the condition of the monitor and the integrity of the wiring connecting the detector device to the monitor. The detector device has an internal radiation source (Am-241) that makes it possible to control the steadiness of the energy calibration. If the self-diagnostic detects any faults, an alarm is triggered.

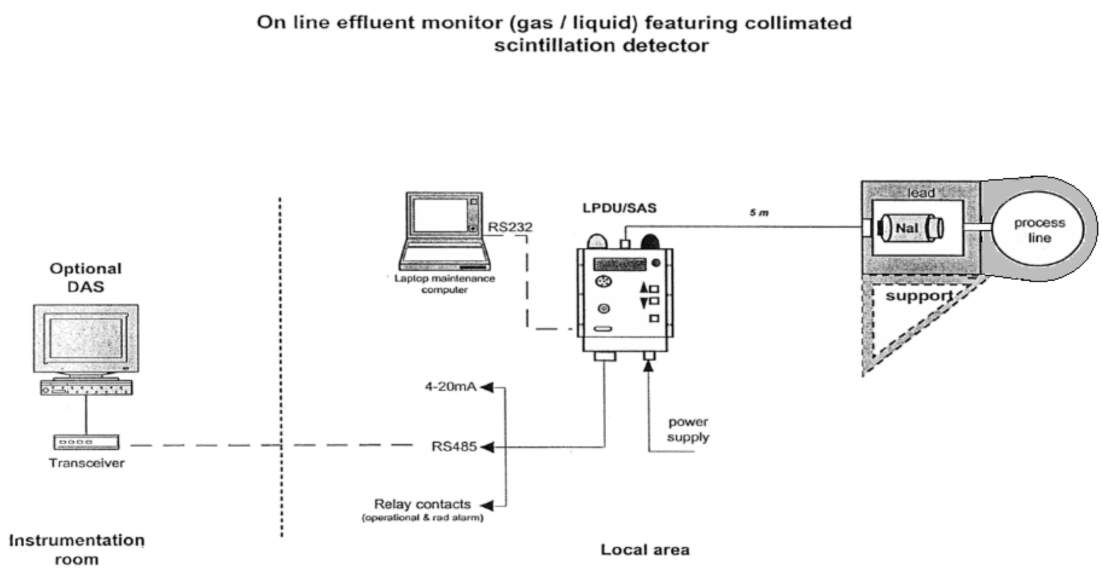

Figure 10 Schematic picture of the ON-line monitor TZ80R0001 (Hiltunen, 2008).

5.1.2 TZ80 Samples in the Laboratory: a review

Under normal operating conditions, operating personnel deliver three 1-liter samples to laboratory once every other week. Two samples are taken either from the tank TZ81B0001 or TZ82B0001, depending on which one is currently filling, and one sample from the sample collection tank. During outage, the amount of sewage increases and the samples are delivered to the laboratory once a week. Additional samples are taken and delivered to the laboratory, if the sample collection tank is about to fill up before scheduled sampling. The operating personnel write the following sample information on each bottle: sampling date and time, and the valve label. Additional information is written on the bottle containing sample from the sample collection tank. This information contains details of the amount of the sewage led into the sea during the sample collection period (CUM), and the volume collected to the sample tank (LTR). Process description describing the process resulting in release report is shown in Figure 11.

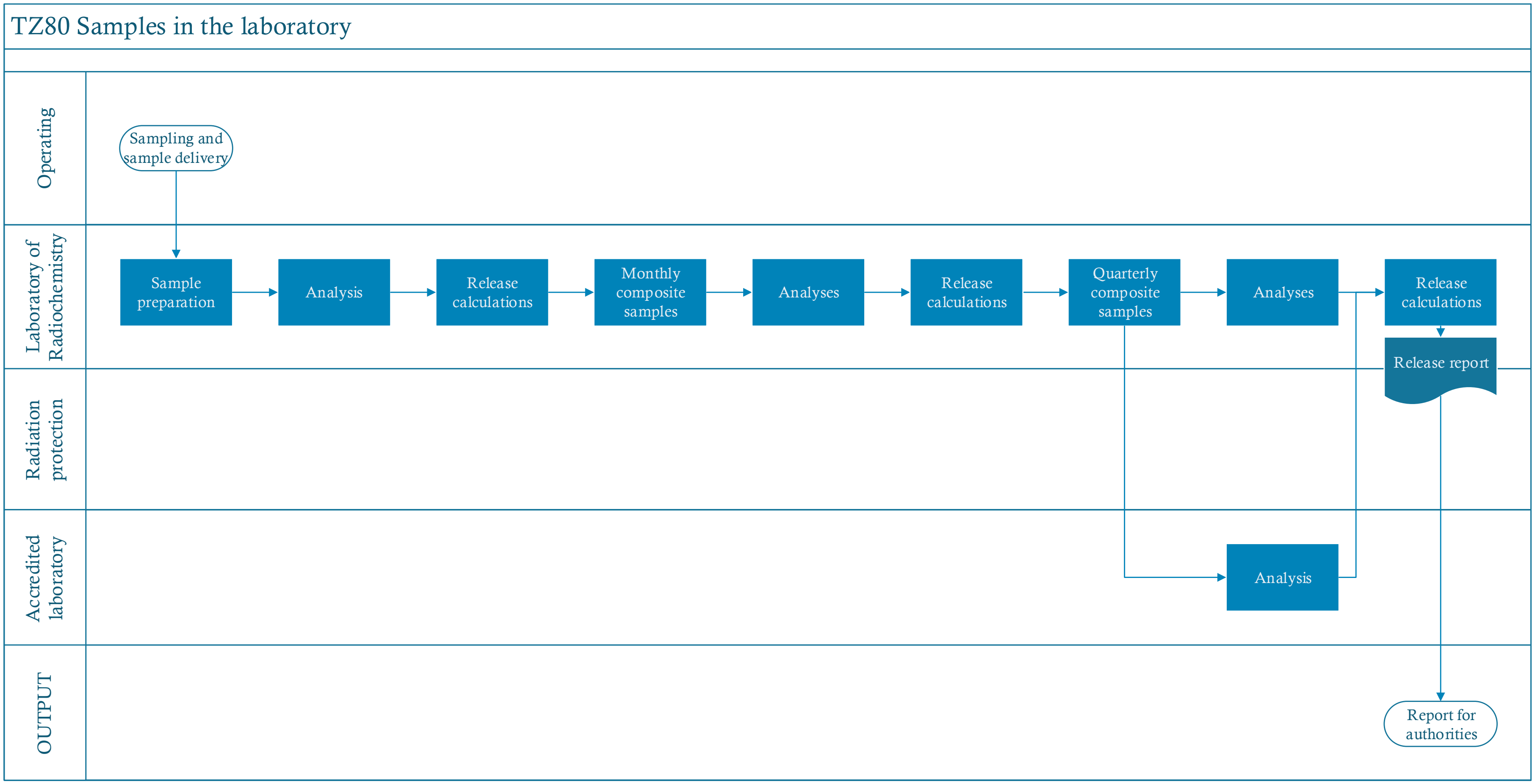

Figure 11 TZ80 samples: process from the sampling to the final release report. Operating personnel take and deliver the samples to the plant laboratory, where laboratory personnel carry out most of the analyses. Final release report is made in collaboration between units.

The laboratory personnel generate the samples to the APEX -gamma spectroscopy software using an IPPA application. All sample information is manually put into the system. This information includes the valve label, the used analyzing code, and the volume information for the sample taken from the sample collection tank. In addition, default values for the measuring geometry and the measuring time are checked. It is also possible to generate samples via laboratory LIMS, LaMDA. To the LaMDA, the valve label, the sampling time and the volume information for the sample taken from the sample collection tank are manually input. After the sample is generated into the LaMDA, the analyzing code is manually inserted for the generated sample. The LaMDA then generates the sample to the APEX with the default geometry and measuring time.

One of the samples from the tank TZ81B0001 or TZ82B0001 is analyzed for gamma activity; the other is stored and disposed of later, if the measuring results of the first bottle are acceptable. The sample bottle is analyzed as a whole, since remaining the bottle unopened is crucial for the successful chemistry analysis later on. If the measured nuclide specific gamma activities meet the exemption limits stated in the Guide ST 1.5, a release report is made based on the achieved results. After this the sample is delivered to the mailroom which forwards the sample to outside laboratory, where pH, conductivity, solid content, total nitrogen content and total phosphorus content are analyzed.

The sample from the sample collection tank is handled as follows: approximately 20 mL of sample is poured into an empty liquid scintillation vial, and the rest of the sample – approximately one liter – is acidified. The valve label and the sampling date are written on the cap of the vial and the vial is stored. The acidified sample is poured into a Marinelli type container. The sample is analyzed for gamma activity and the results are automatically transferred to the laboratory LIMS. The laboratory personnel check the results given by the APEX-software by manual analysis of the gamma spectrum and correct them if necessary. They also check if the results are logical and the analysis meets the set demands. The volume information, CUM and LTR, are filled into an excel sheet, where the released volumes are calculated. From the same excel sheet, the personnel check that the sample collection has been successful. The release calculations for gamma activity are made in the LIMS and the sample is approved. After approving, the sample is poured from the Marinelli back into the sampling bottle and the bottle is stored.

At the end of each month, a monthly composite sample is manually generated to the LIMS. For this sample, release calculations for gamma activity are done. Before making the calculations, laboratory personnel must ensure that the release calculations for gamma activity are performed for each individual sample. In addition, tritium activity and the total alpha activity releases need to be calculated. Therefore, tritium and total alpha activity samples are prepared from the stored samples.

Two monthly composite samples are composed of the stored samples. One composite sample is composed of unacidified samples, collected in the liquid scintillation vials, and the other is composed of the acidified samples stored in the 1-liter bottles. Before composing the sample, a proportional release volume is calculated for each individual sample. This is done in an excel sheet built for this purpose.

Tritium is analyzed from the unacidified composite sample. Composing of the unacidified composite sample is done as follows: from every stored liquid scintillation vial, the calculated, proportional volume of the sample is pipetted into a new vial. After the pipetting, the new vial contains sample proportional to the monthly total release. From this sample, the tritium sample is then made into a plastic vial, using scintillation cocktail. The sample is analyzed in a liquid scintillation counter and results are filled in to the LIMS, and the release calculations for tritium are made.

The total alpha activity is analyzed from the acidified composite sample that is composed as follows: from every stored one-liter sample, proportional volume of sample is measured to a new one-liter bottle. After the new bottle contains sample proportional to the total release of the month, it is mixed and the total alpha activity sample is prepared into a glass vial, using liquid scintillation cocktail. Rest of the one-liter composite sample is stored. The sample is analyzed in the liquid scintillation counter and the results are filled in to the LIMS, and the release calculations for total alpha activity are made.

From the monthly, acidified composite samples, quarterly samples are composed at the end of each quarter. The one liter acidified proportional composite sample is sent to the accredited laboratory, where Sr-89/90 is analyzed.

5.1.3 TZ80 Release Calculations

Release calculations are done for the sample taken from the sample collection tank. The calculations are done in three steps: 1) Always after the biweekly (or weekly during outage) sample has been analyzed, 2) monthly after the monthly composite sample has been analyzed and 3) quarterly after all monthly samples of the quarter have been analyzed. Performing the steps in correct order is essential, since the calculations of the next step need the results from the previous step in order to obtain the correct calculation results. The results are reported to Finnish Radiation and Nuclear Safety Authority quarterly.

For the sample taken from the sample collection tank, CUM and LTR information is filled in an excel sheet, where released volumes are calculated. In addition, the ratio between the drained sewage and the sewage collected into the sample collection tank is also calculated in the same Excel file. The correct operation of sample collection system is monitored this way.

After the released volume is calculated, the release calculations can be done in the LaMDA. At first, the gamma activity results are checked and each trend is monitored. The results are corrected if needed and any exceptions detected in the trend monitoring are investigated. Release calculation is chosen and the program asks for the amount of released volume which is then filled in. The release calculation calculates the overall releases as well as nuclide specific releases. After this the sample is approved.

After each month, the monthly composite sample is generated to the LaMDA. The sample generation searches TZ80-samples from that month from the database. The search finds only the samples, for which the release calculation has been performed. The release calculation calculates the overall releases as well as nuclide specific releases as a sum of the individual samples. Tritium and total alpha activity results are manually added to the sample and release calculation for tritium and for total alpha activity is calculated. The program uses the same volume information provided in gamma activity calculation to calculate the tritium and alpha releases. After these calculations, the sample is approved.

Quarterly release calculation is very similar to the monthly one: The sample generation in the LaMDA searches the samples of the quarter from the database and release calculations are then made. Only manually input information is the Sr-89/90 -result that is obtained from the accredited laboratory when the results are ready.

The results are reported to Finnish Radiation and Nuclear Safety Authority quarterly. The quarterly release report is generated using a special excel file. This excel searches the calculated releases from the LaMDA-system. In addition, the MDA (minimum detectable amount) report is nowadays generated from the MDA results obtained from the LaMDA. Excel returns on default the average MDA values, but also i.e. medians are possible to return. The obtained MDA values are compared with the limits stated in the Guide YVL C.3.

Finally, several people review the report and a meeting concerning the releases is held before sending the report for the authorities. Sr-89/90 result is reported afterwards, when the results are obtained from the accredited laboratory.

5.2 Control tanks TD/TR

Control tanks TD and TR are part of water treatments systems. The system located in the plant unit 2 treats the borated waters of the primary circuits of both units, whereas the system located in the plant unit 1 treats the sewerage waters of both units. The water treatment system works on a batch process principle, and the cleaning process is started when there has been enough water collected to be treated. The cleaning is carried out by evaporation and ion exchange. In the plant unit 2 the result of the treatment is concentrated borated water (40-44 g H_3BO_3/ kg H_2O) that is reused in the primary circuit. In the plant unit 1 the resulting sewage concentrate is led to the treatment plant of liquid wastes for further processing. (Jurvanen, 2012).

The clean condensate from both systems are led to the control tanks of the plant in question. There are four control tanks in each plant unit, named TR41B0001, TR42B0001, TD41B0001 and TD42B0002. Each tank has a volume of 70 m^3, from which approximately 68 m^3 is usually used. In the plant unit 2, the tanks TD/TR42B0001 are used as a storage tanks for concentrated borated water. The process description is shown in Figure 12.

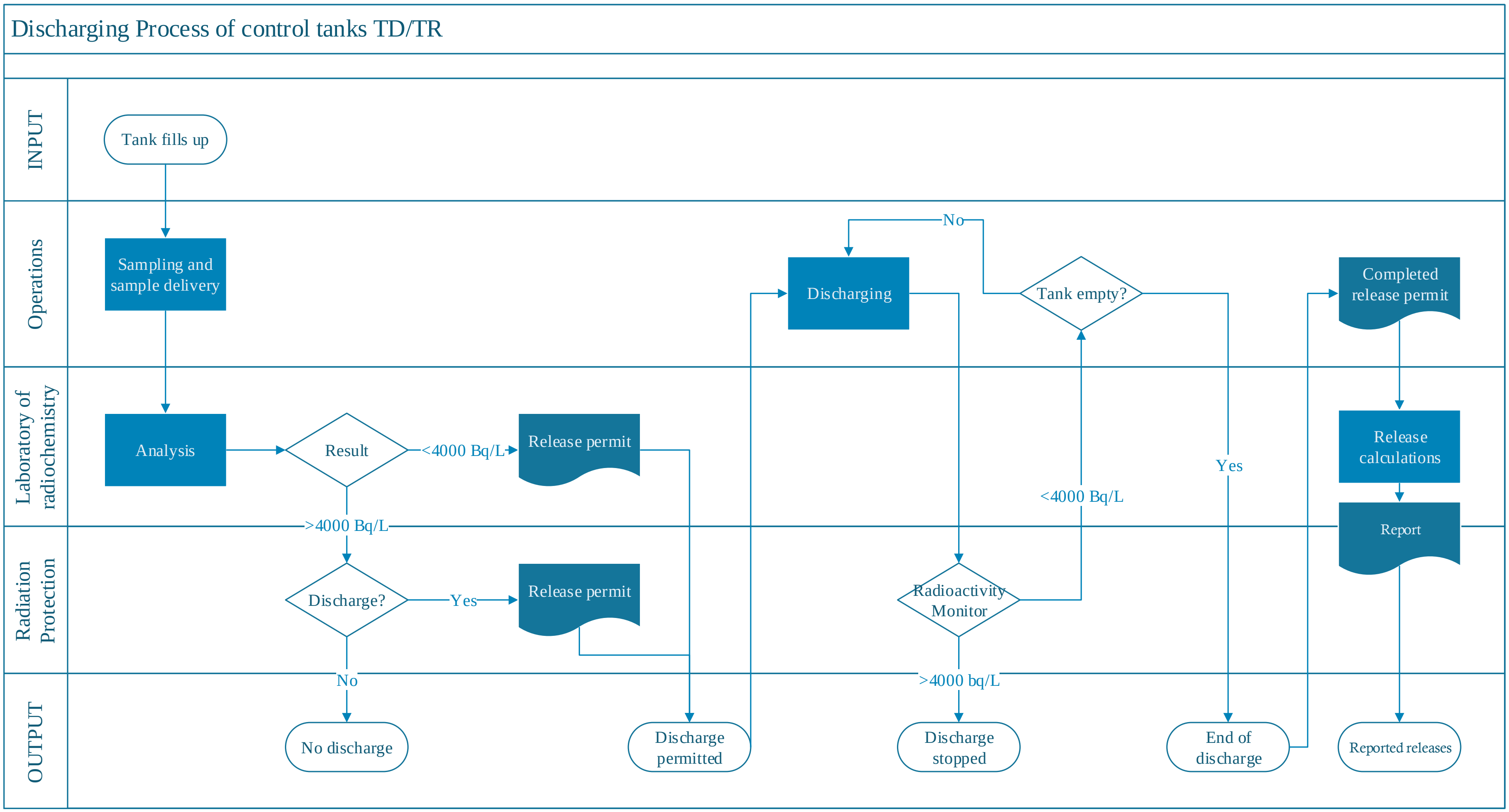

Figure 12 Discharging process of control tanks TD/TR.

The evaporation process is a relatively long process and the filling of one control tank takes approximately ten hours. After a tank is filled up, operating personnel takes two 1-liter samples from the filled tank. The sampling point is located on the side of the tank. The sampling line is flushed before sampling and also the empty bottles are flushed with the sample water prior to the sampling. If the time interval between the tank filling and the sampling is relatively long, the tank content can be mixed using bubbling. Each tank has level indicators with an alarm function and the readings are available in the control room.

The samples are delivered to the laboratory. Unlike in the case of the TZ80-system, the control tanks TD/TR are not drained automatically. The discharging process is started only after an authorized person has issued a written release permit to the control room. Usually this authorized person is the laboratory technician. Permit can be issued by authorized laboratory personnel, when radioactivity of the sample has been analyzed and the result is below the release limit 4,000 kBq/m^3. If the result exceeds the release limit, the only authorized person is the head of the radiation protection unit (Mäkinen, 2015). After receiving the permit, the operators can open the outlet valve of the tank to be drained and water is fed towards radioactivity monitor TR40R0001 and towards the sea. The radioactivity monitor TR40R0001 functions here as a fail-safe and stops the draining if the monitor reading exceeds the set alarm limit 4,000 kBq/m^3. Triggered alarm closes the main valve as well as the outlet valves of each tank. Water exceeding the activity limit can be drained into the sewerage system, where also the possible overflow of the tanks is collected. Control tanks must always be drained one at a time. (Jurvanen, 2012).

In addition, in the plant unit 1 there is a leakage monitoring system before the main valve: there is a small container attached into the bottom of the vertical part of the pipeline. The container has a level indicator, which gives an alarm signal as an indicator of leakage of one or several of the outlet valves of the control tanks. (Jurvanen, 2012).

5.2.1 Radioactivity Monitor TR40R0001

When compared with the radioactivity monitor TZ80R0001, the main difference here is that TR40R0001 is an off-line monitor, where part of the main stream is led via the sample chamber of the monitor. Volume of this chamber is 4.4 liter and the detector is in the middle of the chamber, but not in touch with the water. Also this monitor has NaI-crystal, but the size of the crystal is 1.25" × 1". The chamber is lead shielded with five centimeters thick lead layer in order to minimize the effect of background radiation. (Hiltunen, 2008).

The monitor reading is daily monitored via process computer. In addition, the on-site check is done in every second week and the correct operation of the device and the relating control functions is checked once in four weeks. The calibration check is done every three months. The self-diagnostic system of the device is as in TZ80R0001. Device malfunction in the monitor triggers the same fail-safe as in the case of exceeding the alarm level.

The sample flow via the sample chamber is powered by the ambient pressure of the process. The sample flow is monitored with a rotameter. The schematic picture of the monitor is presented in Figure 13.

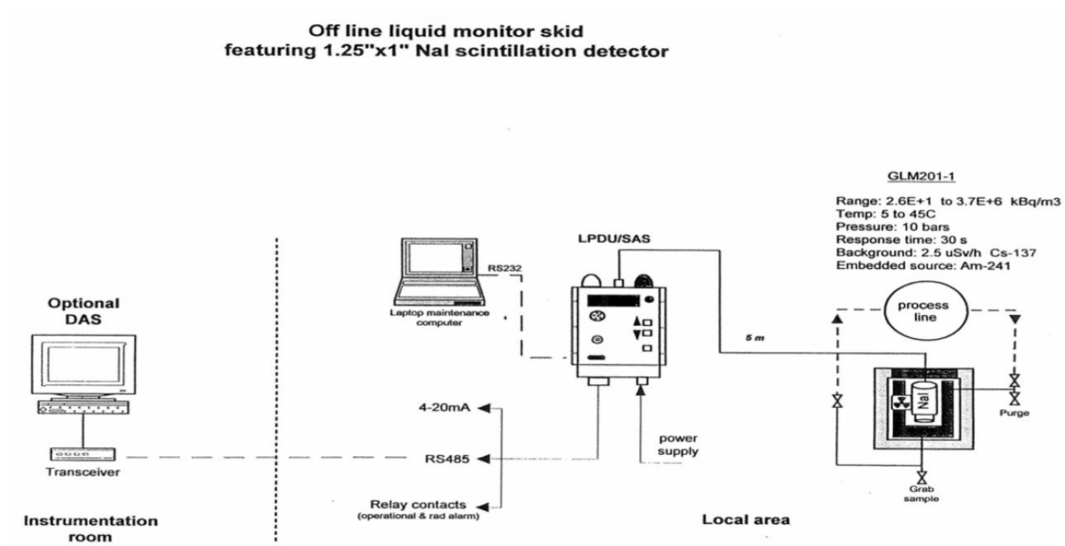

Figure 13 Schematic picture of the OFF-line monitor TR40R0001 (Hiltunen, 2008).

5.2.2 TD/TR Samples in the Laboratory: a review

The operating personnel deliver two 1-liter samples to laboratory as the tank has filled up. The operating personnel write the following sample information on each bottle: sampling date and time, the tank label and sometimes also the valve label. The other sample is used for radiochemical analysis, as the other sample is used for the determining of the conductivity and the pH of the sample. The sample used for radioactivity analysis is acidified by adding 6.5 mL of concentrated nitric acid per one liter of sample.

Similarly, as in the case of TZ80-samples, the laboratory personnel generate the samples to the APEX -gamma spectroscopy software using an IPPA application. It is also possible to generate samples via laboratory LIMS, LaMDA.

The acidified sample is poured into a Marinelli beaker. The sample is analyzed for gamma activity (results given by APEX-software are checked with manual spectrum analysis as in case of TZ80) and the results are automatically transferred to the laboratory LIMS. After approving, the laboratory worker creates the release permit in LaMDA and sends it via e-mail to the control room. The permit is also printed and signed, and stored in the laboratory. The analyzed sample is poured from the Marinelli back into the sampling bottle and the bottle is stored. Also the unacidified sample is stored after the chemical analysis. The process description is presented in Figure 14.

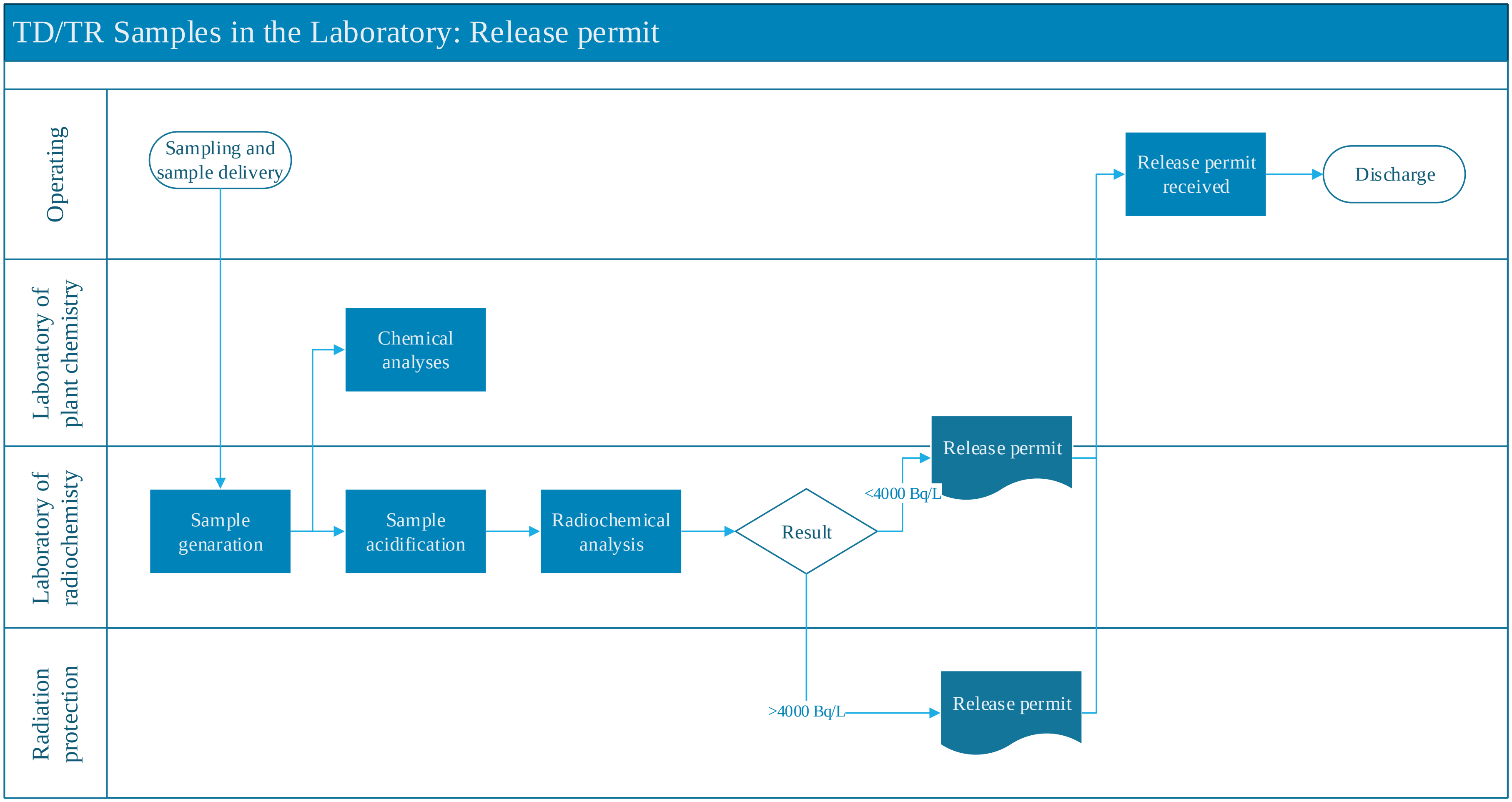

Figure 14 Before the discharge can begin, release permit is needed. Operating personnel takes the samples and delivers them to the laboratory. Release permit is based on the result of the radiochemical analysis, where the gamma activity of the sample is analysed.

After the tank has been discharged, the operators send the release permit back to the laboratory with their signature and information about the discharged volume and the discharge time. With this information the laboratory personnel can perform the release calculations. After the release calculations are done, the amount of sample, proportional to the total discharge, is poured from the 1-liter bottle into a bigger container in order to form a monthly composite sample. For unit 1 samples, this relation is 5 ml of sample per discharged cubic meter, and for unit 2 the relation is 10 ml of sample per discharged cubic meter. There are own containers for each month and the samples of the different plant units are kept separately.

At the end of each month, a monthly composite sample for each plant unit is manually generated to the LIMS. For this sample, release calculations for gamma activity are done. Before making the calculations, laboratory personnel must ensure that the release calculations for gamma activity are performed for each individual sample (all the permits have been returned from the control room). In addition, tritium activity and the total alpha activity of the releases need to be calculated. Tritium and total alpha activity samples are prepared from the stored samples.

Tritium is analyzed from the unacidified composite sample for each plant unit. From the composite samples, the tritium samples are made into a plastic vial, using liquid scintillation cocktail. The samples are analyzed in a liquid scintillation counter and results are filled in to the LIMS, and the release calculations for tritium are made.

The total alpha activity is analyzed from the acidified composite sample for each plant unit. The samples are made into a glass vial, using liquid scintillation cocktail. The samples are analyzed in the liquid scintillation counter and the results are filled in to the LIMS, and the release calculations for total alpha activity are made. The composite samples are stored.

From the monthly composite samples, quarterly samples are composed at the end of each quarter. The one liter acidified proportional composite sample is sent to the accredited laboratory quarterly, where Sr-89/90 is analyzed.

5.2.3 TD/TR Release Calculations

The release calculations are made similarly to the release calculations of TZ80. The exception is that in this case, the added information is discharged volume and the discharge time (obtained from the control room). The process description for release calculations is presented in Figure 15.

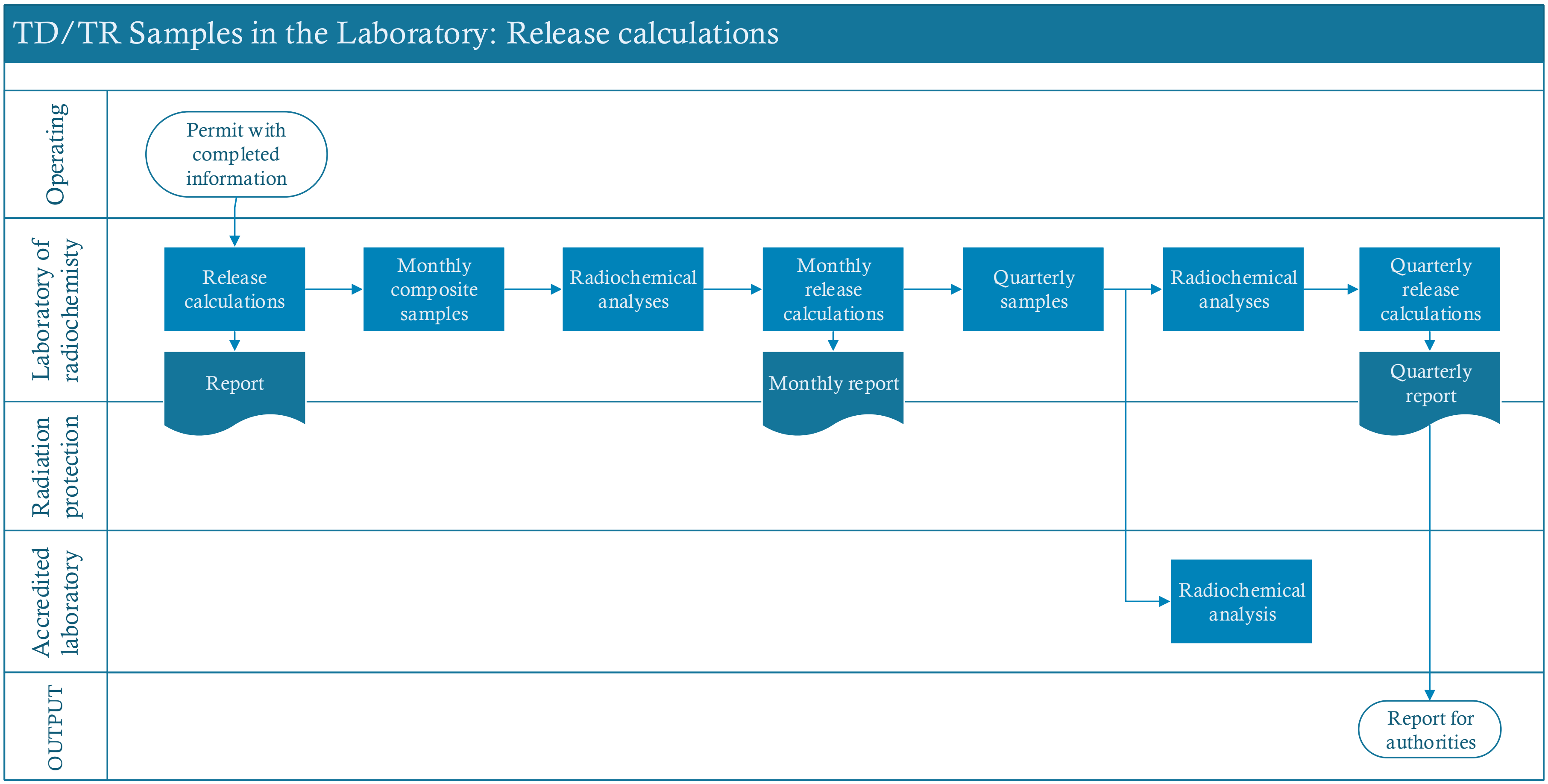

Figure 15 Process description of the release calculations for TD/TR samples**.**

5.3 Ventilation Stack TL00

The Loviisa NPP has one ventilation stack that is divided between the two units by a wall. The exhaust air from the containment buildings and auxiliary buildings of both plants is discharged via the ventilation stack. In addition, the air from the fuel building is discharged via the discharge route of the unit 2 and the air from the treatment plant of liquid wastes is discharged via the discharge route of the unit 1. Otherwise the described discharge processes are similar for both plant units.

As seen in Figure 16, the outlets of different ventilation systems are collected together in a collecting chamber, from which the exhaust air travels to the stack. Before the vertical part of the stack there is a horizontal part a diameter of 3.3 meters. In this horizontal part, there are two flow indicators, two multi-nozzle probes and two dose rate monitors installed. These monitors are used in a case of a nuclear accident and are therefore not discussed in this thesis. Also the monitor TL00R0003 is used as an accident monitor, but during the normal operation conditions it works as a parallel monitor for the monitor TL00R0001. (Hiltunen, 2008).

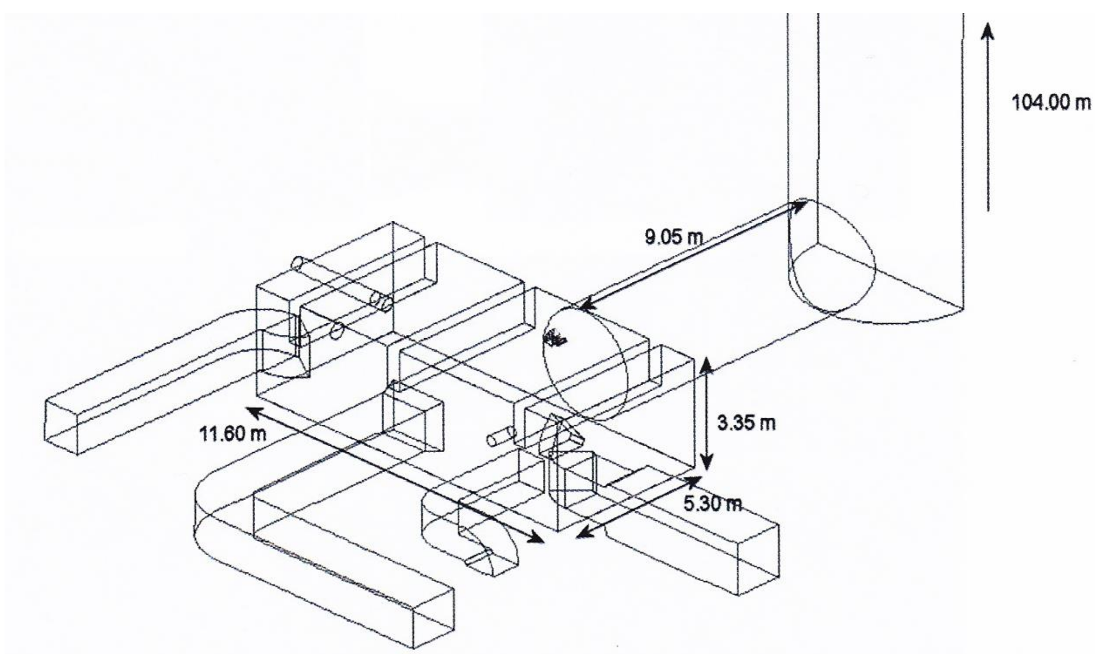

Figure 16 Geometry of the collecting chamber and lower part of the ventilation stack of the plant unit 1 (Rämä, 2012).

The flow indicators TL00F0001 and TL00F0003 are located several meters from the collection chamber. The indicator TL00F0001 is a wing wheel anemometer located in the middle of the cross-section of the pipe. The indicator TL00F0003 is located slightly aside from the middle of the pipe and it is a thermal anemometer. With these indicators, the total volume of the exhaust air is evaluated.

The multi-nozzle sampling probes collect the sample for radioactivity monitors TL00R0001 and TL00R0003. The first one is located several meters after the collection chamber and collects air sample for radioactivity monitor system TL00R0001. Another sampling probe collects air sample for radioactivity monitor TL00R0003 and it is located two meters behind the first probe. The sampler is a rake that has four branches and four nozzles in a brand, making together 16 nozzles in one sampling rake. The monitoring systems are located in a room just below the stack.

From the sample streams TL00R0001 and TL00R0003 many parameters are measured: In TL00R0001 there are continuous measurement of radioactive substances bound to aerosols (hereby called only as *aerosols*), iodine and noble gases. In addition, there is also accumulating collection of aerosols, iodine, tritium, strontium, alpha emitters and carbon-14 in special filters or accumulators that are analyzed in laboratory weekly or quarterly. The radiation protection personnel change the filters of aerosols and iodine weekly, and deliver the samples to the laboratory of radiochemistry. The laboratory personnel change the accumulators of tritium and carbon-14 weekly and analyze all the samples in the laboratory. In addition, the laboratory personnel collect a noble gas sample in a 4.3 liter Marinelli beaker and analyses it weekly. In TL00R0003 there is only a continuous monitoring of noble gases, but the accumulators are the same as in TL00R0001. The noble gas grab sample is not collected under normal conditions from this sample stream.

5.3.1 Radioactivity Monitors TL00R0001 and TL00R0003

The radioactivity monitors TL00R0001 and TL00R0003 are so called combination monitors, meaning there are several separate monitors in series. The schematic picture of the monitor TL00R0001 is presented in Figure 17. The sample stream is collected from the stack flow by the 16 nozzles of the first sampling rake. The stream is divided into two parallel streams as seen in Figure 17 and the nominal flow rate of the parallel sample streams is 35 liters per minute (total flow 70 liters per minute). The other of the parallel streams is for a continuous monitoring, and the other is for a continuous sampling of aerosols and iodine.

In the continuously monitored stream, there is first a particulate monitor TL00R011. In the particulate monitor, the aerosols in the air are accumulated in an aerosol filter, which works with a filter cassette principle. The old filter is automatically replaced with a new one, as the pressure difference between the front and the back of the filter starts to indicate filter clogging. The filter is monitored with a semiconductor detector detecting beta radiation. The monitor is lead shielded in order to minimize the effect of background radiation. In addition, the monitor has an internal Cs-137 source for functional testing.

After the particulate monitor TL00R011, there is an iodine monitor TL00R0021. Similarly, to the particulate monitor, the iodine (both elemental iodine and organically bound iodine) is accumulated in an iodine filter, which is a filter cartridge filled with activated carbon. The iodine activity in the filter is monitored with a semiconductor detector (NaI-crystal). Also this monitor is lead shielded and has an internal Cs-137 source.

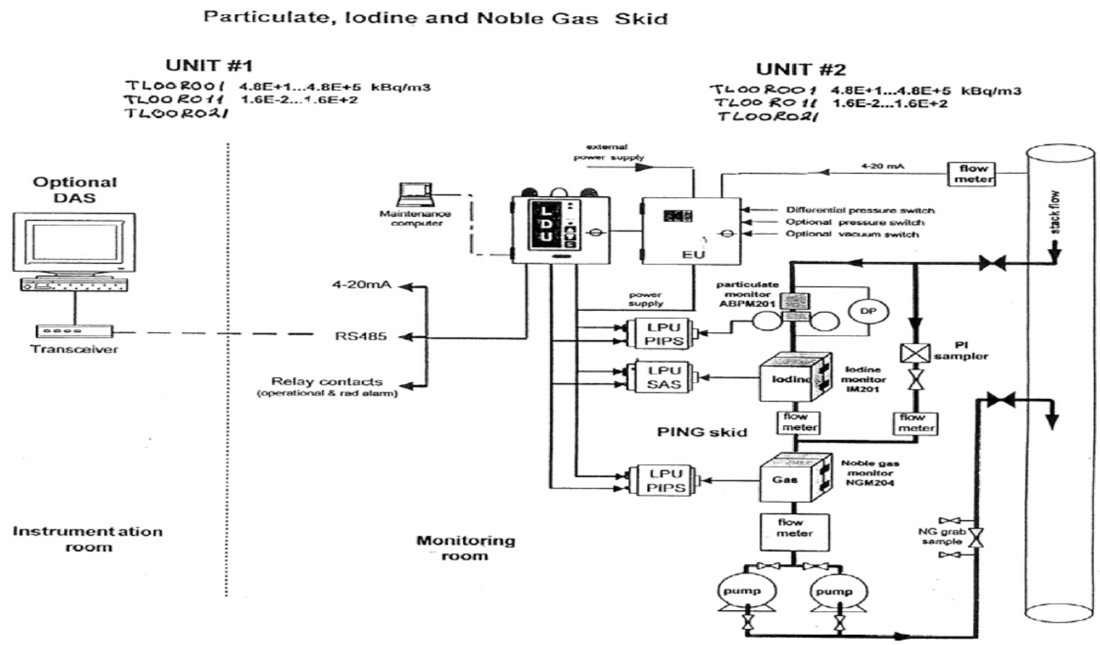

Figure 17 Schematic picture of the OFF-line monitor TL00R0001 (Hiltunen, 2008).

In the sampling stream, there is a capsule containing aerosol and iodine filters in series. The sample is collected in these laboratory filters and the filters are replaced with new ones weekly or in a case of any monitor alarm. The filters are analyzed in the plant laboratory within a short time interval in order to be able to detect all short-lived nuclides. After particulate and iodine monitoring, the parallel streams are combined. The noble gas activity in the whole stream (now with a flow rate of 70 liters per minute) is continuously monitored, with a semiconductor detector detecting beta radiation. The detector is located in a measuring chamber of 0.3 liters. Chamber and detector are led shielded.

After these radioactivity monitors, there are two parallel pumps to enable continuous operation in an event of a pump failure or scheduled maintenance procedures. After the pumps, there is a sampling point, where laboratory personnel collect a noble gas sample of 4.3 liters weekly. The sample Marinelli with quick-connect fittings is connected to the system and the main stream is restricted in order to get part of the sample stream to flow through the Marinelli. The stream is restored after sampling period of five to ten minutes and the noble gas sample is delivered to the laboratory for instant analysis.

The last part of the sampling stream TL00R0001 in the plant unit 2, is an accumulation equipment of carbon-14 and tritium. The flow diagram of this accumulation equipment is presented in Figure 18. In the plant unit 1, the similar accumulation equipment is located as a part of sampling stream TL00R0003. In this phase, a part of the main sample stream is pumped in to this equipment at a flow rate about 10 liters per minute. Before the pump, there is a PTFE filter (not shown in the figure) with pore size 0.2 μm to screen possible small particles that could be harmful to the equipment. From this flow of 10 liters per minute, approximately 0.1 liters per minute is led towards the actual accumulation unit K-1.

Before the accumulator, the flow is led to a reactor, where the carbon and hydrogen compounds in the sample are oxidized in a catalytic reaction (catalysts Cu_2O, PdO and PtO_2) at 600 °C, into carbon dioxide and water. The unit K-1 is a detachable pipe-shaped container, filled with zeolite pellets. The unit has quick-connect fittings in order to provide easy attachment and detaching, and to remain the unit sealed when not connected. Water and carbon dioxide are adsorbed in to the zeolite. The laboratory personnel change the unit to unloaded one usually weekly, when the total sample volume is approximately one cubic meter. However, as the adsorption equilibrium in this case is highly towards the water, the reliable accumulation of carbon dioxide cannot be granted if the mass of the accumulated water in one sampling period exceeds ten grams. For this reason, the unit has to be replaced more often if the humidity of the air is high, usually this is the case during summer months. Information about pressure, flow rate, temperature and humidity are recorded and monitored in a computer located at near proximity to the equipment. The laboratory personnel print the information about one sample collection period when changing the accumulator unit, and starts a new recording period after the loaded unit is replaced with an unloaded one. The air is returned to the original sample stream and further to the stack.

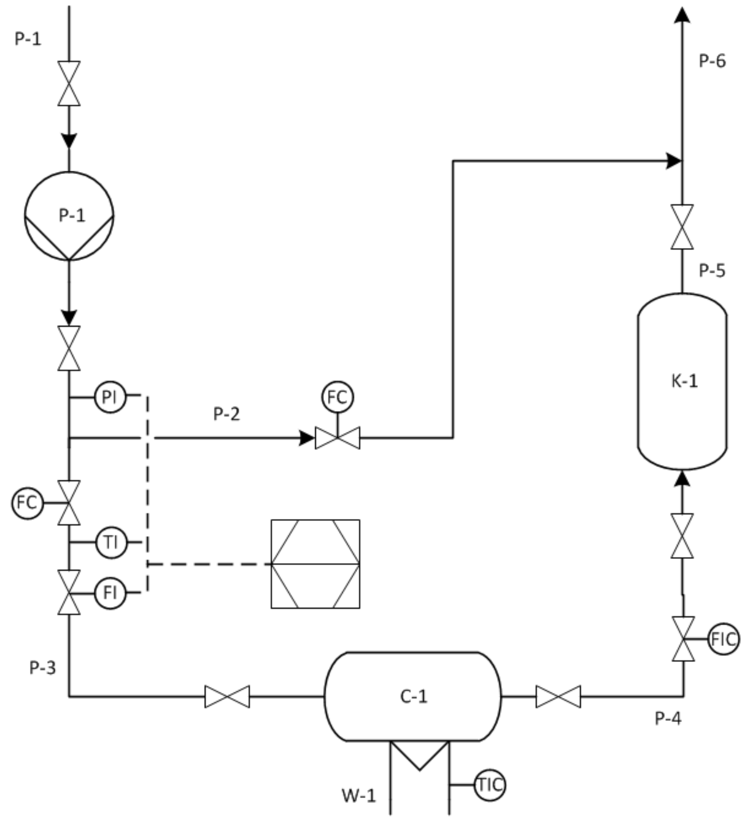

Figure 18 Schematic flow diagram of the sampling equipment of C-14 and H-3 (Leinonen, 2014).

The radioactivity monitor TL00R0003 has only one stream and the nominal flow rate is 35 liters per minute. The sample stream is collected from the stack flow by the 16 nozzles of the second sampling rake. The schematic picture the monitor TL00R0003 is presented in Figure 19. First there is particle and iodine sampler that is a capsule containing aerosol and iodine filters as in the TL00R0001. These filters are changed to new ones weekly or in a case of a monitor alarm. The sample flow to the monitors is stopped during the changing of the filters. It is worth mentioning, that both filters in the TL00R0001 and in the TL00R0003 must be changed always at same time, in order to analyze the releases correctively. This is discussed in detail in the next chapter. After the filters are changed, they are analyzed in the laboratory as soon as possible.

After the aerosols and iodine has been filtered from the stream, the noble gases are monitored. The noble gas monitor TL00R0003 is a continuous noble gas monitor, where the stream is led to the led shielded ionization chamber of 0.1 liters.

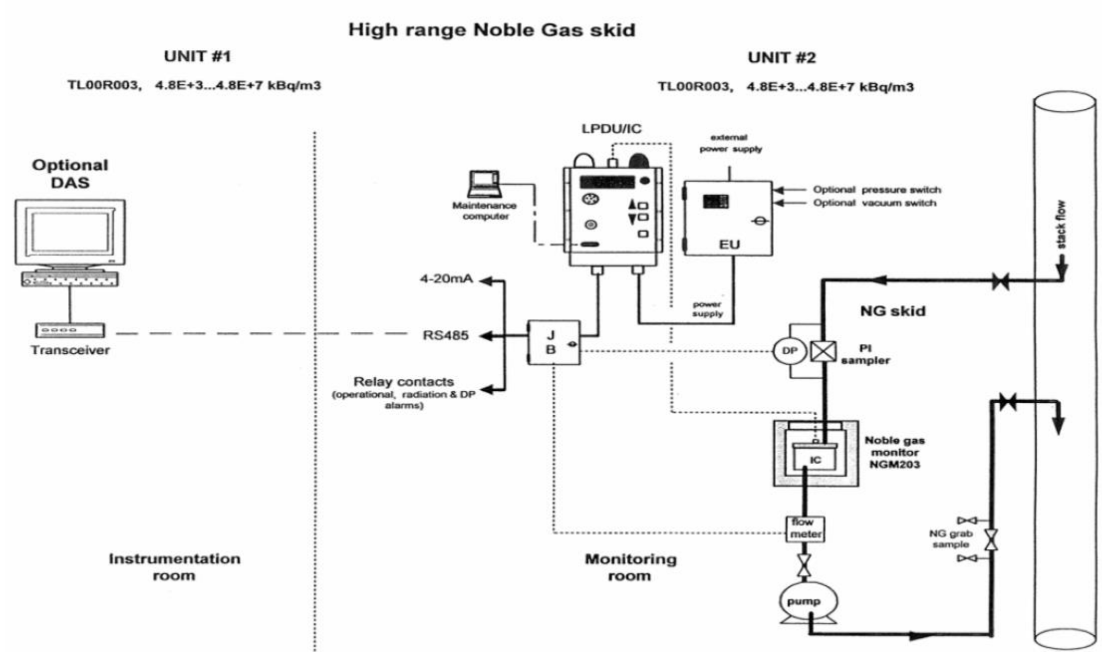

Figure 19 Schematic picture of the OFF-line monitor TL00R0003 (Hiltunen, 2008).

The readings of the continuous radioactivity monitors are monitored in process computer during weekdays by the radiation protection personnel. The radiation protection personnel follow the trend charts and based on the observed changes in the trends, possible problems can be noticed before the actual malfunction of the device. The operational personnel monitor the possible alarms and other deviations continuously and alert the radiation protection and radiochemistry personnel in a case of any alarms or deviations. Possible repairs or other maintenance tasks are performed by automation maintenance personnel. (Kontio, 2013; Hirvelä, 2013).

The radiation protection personnel perform several scheduled inspections for the radioactivity monitors. Along with the daily trend monitoring, an on-site check is done every other week. In this check, the overall condition of the monitoring equipment is inspected and also the possible alarms or notifications in process computer are checked. If any alarms or notifications are present, it is ensured that the needed actions are taken. In addition, the functional testing of the monitors is done every fourth week. The energy calibration of the monitors is checked in every 26th week with one or more radiation sources. The recalibration is performed by the automation maintenance personnel, if needed. (Hirvelä, 2013).

The laboratory of radiochemistry is in charge of the sample collection equipment for capturing H-3 and C-14. The laboratory personnel perform an overall check for the equipment always when changing the accumulation unit. Also, the equipment is checked for possible leakages in every six months. (Lampén, 2014).

5.3.2 TL00 Samples in the Laboratory: a review

The gamma activity in the noble gas samples (TL00R0001, sampling by the laboratory personnel), the gamma activity in the aerosol and iodine filters (TL00R0001 and TL00R0003, changing of the sampling filters by the radiation protection personnel) and the beta activity in H-3 and C-14 samples (TL00R0001, sampling by the laboratory personnel) are analyzed weekly for both plant units. Total alpha activity, total beta activity, and Sr-89 and Sr-90 in the aerosol samples is analyzed quarterly for both plant units from stored aerosol samples.

As the radiation protection personnel change the aerosol and iodine filters of TL00R0001 and TL00R0003, the old filters are sealed in a clean envelope and delivered to the laboratory of radiochemistry. The laboratory personnel generate the samples via laboratory LIMS, LaMDA using same sampling time for both monitors. For example, if the sample TL00R0001 is taken at 08:03 and the sample TL00R0003 at 08:07, the time 08:05 is chosen for the sampling time. Usually the filters of the plant units 1 and 2 are changed in separate days. The analyzing codes for aerosol filter and for iodine filter are manually inserted for the generated sample. The sample amount (air volume) is obtained automatically from the process data. Samples are then analyzed for gamma activity. After receiving and checking the results, the aerosol filters are stored in the original envelopes for later alpha, beta and Strontium analyses, and the iodine filters are disposed.

The laboratory personnel take the noble gas sample and generates the sample using the LaMDA. The sample is measured for gamma activity in two phases: First the sample is measured for a shorter time in order to detect the short-lived nuclides and then the longer measurement is done. The results are automatically transferred to the LaMDA-system. The laboratory personnel check the results and correct them if necessary.

The C-14 and H-3 samples from both plant units are generated to LaMDA as TL00R0003-samples. The sample containers are desorbed and regenerated with a special equipment shown in Figure 20. At the beginning of the desorption, only the outlet of the sample container is opened towards the cooling bath, and the furnace is heated up to 420 °C during a time interval of 40 minutes. When the temperature has reached the 420 °C and the bubbling in the tube 3. is decreased, the inlet of the sample container is connected with a nitrogen supply. The flow is then adjusted to point, where there appears approximately one gas bubble per one second in the tube 3. The water is collected in the gas washing tube 2 in a solid form (temperature -25 °C) and the carbon dioxide is absorbed in the special solution in the gas washing tube 3. The temperature is held at 420 °C for three hours and then the furnace is let to cool down. The gas washing tubes can be detached for sample preparation as temperature of the furnace is close to 150 °C. The nitrogen flow is continued until the furnace has reached the room temperature and the sample collector is ready for the next use. The hose connecting the sample collector and the gas washing tube 2 is flushed with desalinated water after the use of the equipment. This prevents the possible tritiated water residue in the hose from contaminating the samples of the next desorption cycle.

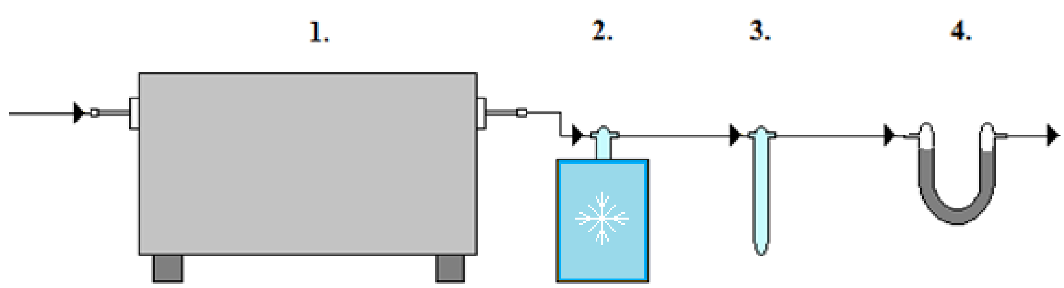

Figure 20 Desorption and regeneration equipment for H-3 and C-14 samples: 1. Tube furnace, where the sample collector is inserted, 2. cooling bath with a gas washing tube, 3. gas washing tube with CarboSorb E solution, 4. U-tube with activated carbon (Leinonen, 2014).

The mass of the water is measured and the sample is let to melt. Tritium is analyzed from this sample. The tritium sample is made into a plastic vial, using scintillation cocktail. The carbon-14 samples are made into glass vials, by dividing the sorbtion solution equally into two vials, and using scintillation cocktail. The samples are analyzed in a liquid scintillation counter and results are filled in to the LIMS, and the release calculations for tritium and carbon-14 are made.

The aerosol filters are analyzed quarterly for total alpha and total beta activity in a proportional counter. The analysis can be done when there has been at least two weeks from the sampling of the last samples. This prevents the short-lived nuclides from interfering with the analysis. After the analysis, the laboratory personnel check the results. The results that fall below the MDA are marked as results below MDA. After this analysis, the aerosol filters are sent to an accredited laboratory, where Sr-89/90 is analyzed. If the aerosol had a total alpha activity result below the MDA, the filter is cut into a smaller size before sending. Otherwise the whole filter is sent to the accredited laboratory, as the alpha analysis needs the bigger sized filter.

5.3.4 TL00 Release Calculations

After the aerosol and iodine filters have been analyzed for gamma activity and results are approved in the LaMDA the release calculation is made. Then, the laboratory personnel create a virtual combination sample that combines the activity results of the analyses. If the samples are not generated with the same sampling time, LaMDA cannot find the results and create the combined sample. For the virtual sample, always the higher nuclide specific results are chosen by the LaMDA. For this sample, the release calculations are made and a report is generated. LaMDA gets the needed volume information from the process data. Quarterly as the results of total beta and total alpha activity are measured, the results are manually inserted for each individual sample and release calculations are made for individual virtual combination samples. If the result falls below MDA, the result is marked as MDA result and the LaMDA does not calculate release result for the concerned parameter. After this, the calculations are made in a similar method for each combined sample. Same is repeated as the Sr-98/90 results are obtained from the accredited laboratory.

For the noble gas results (TL00R0001), release calculation is made after the results are checked and corrected. Volume information is obtained from the process data and the obtained calculation results are approved and a report is made.

After the analyses for C-14 and H-3, the results are manually inserted to the LaMDA-system. For this the laboratory personnel uses the volume information recorded by the computer attached to the sample collecting device. Usually for the sampling time of one week, this volume is below one cubic meter. For the tritium, also the mass of the collected water is inserted. The value for the overall flow is obtained automatically from the process computer. For these samples (TL00R0003), release calculations 4830 (for C-14) and 4810 (for tritium) are done. Samples are approved after the calculations are done.

After each month, the similar monthly composite sample is created in LaMDA as in the cases of TZ80 and TD/TR. For this sample, all the release calculations are done. Also the generation of the quarterly sample follows the same principles as the TZ80 and TD/TR samples, including the quarterly reporting to STUK. The process description is shown in Figure 21.

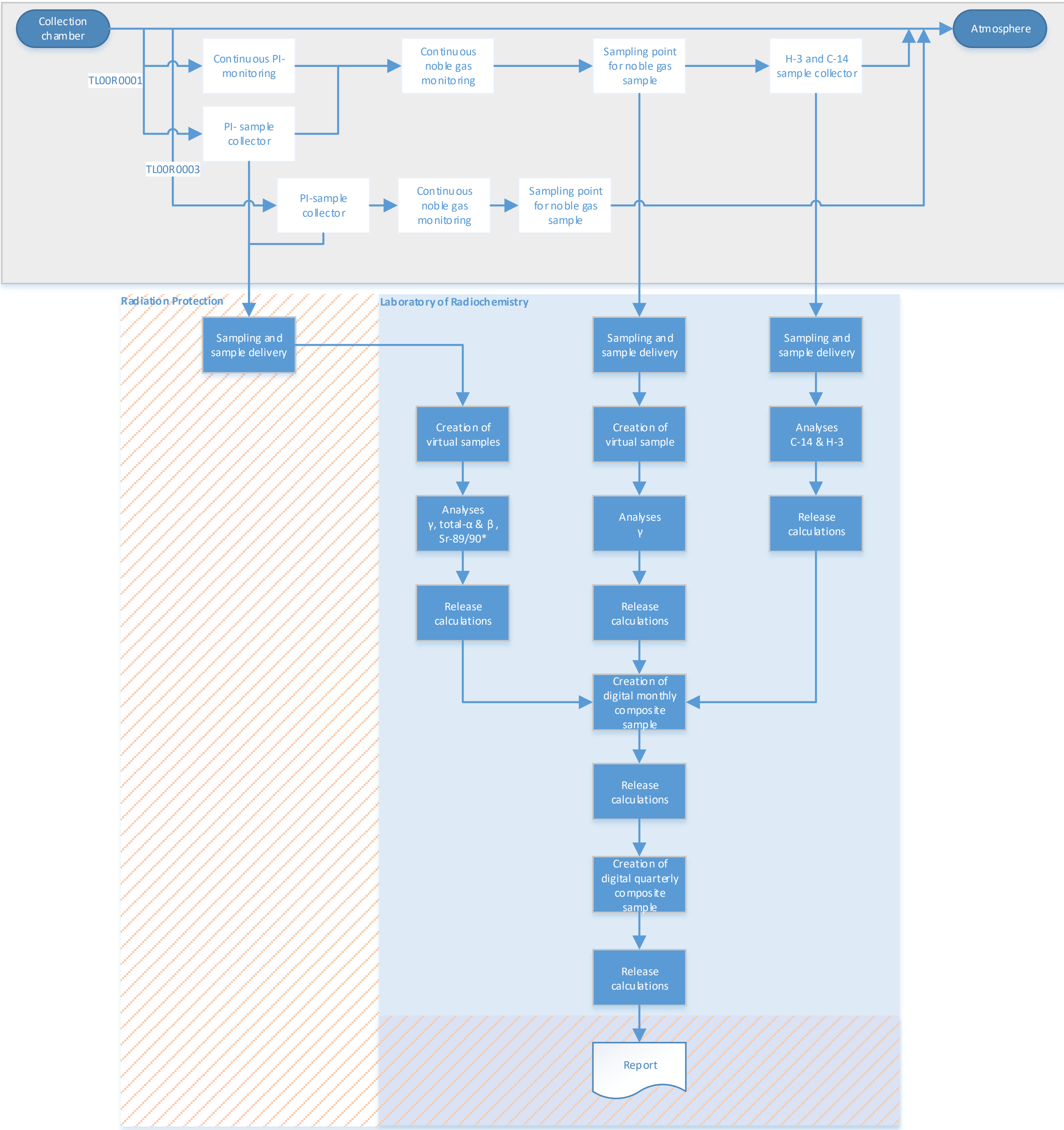

Figure 21 Process description of TL00-process. Particle and iodine filters are changed and delivered to the laboratory by radiation protection personnel. The sampling and sample delivery of the noble gas samples and C-14 and H-3 is done by laboratory personnel. * Sr-89/90 analysis is carried out in an accredited laboratory.

6 DETECTED PROBLEMS CONCERNING THE CURRENT MONITORING OF RADIOACTIVE RELEASES

Detected problems were divided into three groups and are presented in following chapters.

6.1 Problems Related to Sampling

The TZ80 system has the proportional sampling system, where the proportional sample is collected in to the sample collection tank. The sampling system has been operational since 2009. The overall principle in this sampling is good and follows several of the guidelines mentioned in the Chapter 4.2.1 Sampling. The pumping of the drained sewerage introduces mixing into the flow and the sampling equipment collects a composite sample in to the sampling tank. Before the actual laboratory sampling, the operating personnel mix the tank volume and flushes the sampling line with the sample. Also, after the sampling, the tank and the sampling line are flushed with clean water in order to prevent the contaminating the next sample batch. In addition, the used activity monitor is an on-line monitor, and the whole flow is measured.

However, the downside with the TZ80 proportional sampling system is the unreliable operation of the system, or to be precise, the long reaction time in a case of any deviations. For example, the operational event report KT38/2014 (Juurmaa & Kuittinen, 2015) describes one event of this kind. In this event, the operating person was taking the samples and noticed that the information on the screen of the sample collection tank was incorrect. On the screen, there should be information about the amount of the sewage led into the sea during the sample collection period (CUM), and the volume collected to the sample tank (LTR). In this case, the flow measurement and LTR information were on the screen, and in addition the LTR information did not correspond to the discharged volumes found in process computer. Overall, the proportional sampling system was not operational for two weeks: it took one week to notice the problem and one week to perform the corrective actions. During this time, the samples for the release calculations were taken directly from the tanks TZ81/82B0001 (using the method used before the installation of the proportional sample collection equipment).

The problem with the system is that all the indicators related to the sampling system can only be observed locally. Especially, this is problematic in a case where there are some problems with the indicator light placed in the corridor outside the room. In addition, the sampling is the only frequent operation that takes place in the room. Because of this, the possible problems can be left unnoticed for a relatively long time (even for two weeks during the normal operation).

The sampling of the control tanks TD/TR lacks many features listed in Chapter 4.2.1 Sampling. The sampling line is flushed before the sampling and the integrity of the sample is preserved during the sample handling, but otherwise the sampling could be an example of Gy's *grab sampling*. The tanks are filled up during a long time period (approximately ten hours per one tank) and the inlet flowrate is relatively low (less than 2 kg/s). The tanks are not mixed prior to the sampling. This has been justified by the fact that the concentration of the radioactive substances in the water is very low, and the mixing proposed by the inlet flow is considered to be sufficient enough. In addition, the particle sizes after the cleaning processes can be assumed to be so small that gravitational separation can be neglected. In addition, the mixing process is considered laborious and it demands the work input of several operating persons. This procedure is also justified by the Finnish Radiation and Nuclear Safety Authority. In comparison, the German Authority Nuclear Safety Standards Commission clearly states in KTA 1504 (2007) that in a similar case the entire content of the tank shall be homogenized by mixing of some sort, prior to the sampling.

The sampling of the TL00 has been studied in many related studies during recent years. The aerosol concentrations and particle distributions have been studied by Hirvelä (2009, 2010, 2012). The laboratory analyses have shown, that the aerosol filter in sample line TL00R0003 receives less radioactivity than the filter in parallel sample line TL00R0001. The sampling rakes are similar for both sampling lines, but the flow into the TL00R0001 is twice the flow into the TL00R0003 (this is due to the continuous aerosol and iodine monitoring in the sample line TL00R0001). The isokinetic sampling of the sampling rake has been calculated based on the greater flow rate of the TL00R0001, and thus the sampling in the TL00R0003 is sub-isokinetic and the bigger particle sizes should be emphasized in the sample. As radioactive aerosols have been studied, it has been noticed that usually the main part of the total radioactivity of the samples is because of the bigger sized particles (Papastefanou, 2008). Therefore, there should be higher concentration of radioactive particles in aerosol filter TL00R0003, but this is not the case.

The performed CFD-simulations (Rämä, 2012; 2013) indicated an area with more homogenous flow profile than where the rakes currently are. An experimental research by Hirvelä (2014) obtained contradictory results, whether increasing the flow into the TL00R0003 evens the concentrate difference or not. Hirvelä (2014) concludes that the reason might lie in structural differences between the monitors, as the structure of the monitor TL00R0001minimizes the losses better. However as mentioned in Chapter 5.3.4 TL00 Release Calculations, the calculations are performed based on the higher results and the reporting does not underestimate the releases.

The problem with testing the representativeness of all of the sampling procedures lies on the fact that the activity concentrations are very low. Reliable measurements are hard to perform as the measuring results are below the MDA limit or very close to it. Obtaining consistent results would require intentional addition of radioactive tracer and therefore contaminating the systems and introducing additional discharges to the environment.

6.2 Problems Related to Human Error

As stated in Chapter 4.2.2 Human Error, the majority of the human error cases were caused by skill-based errors. As stated by The Health and Safety Executive (HSE), this error type is often common among highly-trained, experienced and well motivated employees. As a common factor in these cases is a disturbance of some kind, which has caused a decrease in attentiveness and in a short-time memory. For example, in the event report KT07/2014 (Jaakkola, 2014) the performing of a routine task was disturbed by a phone call and in the report KT44/2014 (Lamminen & Kuittinen, 2015) distribution of responsibilities among the laboratory employees was unclear due to exceptional meetings and trainings that happened to take place during that day. In addition, KT45/2015 (Kuittinen, 2014) and KT58/2009 (Solja, 2009) were clearly cases, where the responsibilities were moved from one organization to another.

In knowledge based errors the common factor was the unusual situation and insufficient preparations. For example, in the event report KT47/2013 (Lamminen, 2013c) tests were performed in TL00 sampling line, and all of the effects of these tests on routine release calculations were not identified beforehand.

The single rule based error in KT14/2012 (Lamminen, 2012) was caused by the employee following unofficial rules instead of the official ones. The unofficial rules should not have been existing.

In the interview mentioned previously in Chapter 4.2.2 Human Error, the personnel of the laboratory of radiochemistry detected the following main issues:

- Working in a hurry: too many tasks to be performed at once. The ability to focus on one task at a time is disturbed by stressing about all the other tasks that are still to be done.
- Disturbances that interrupt the work flow: incoming phone calls, meetings, coworker asking questions at a wrong time.
- Prioritizing the tasks: to detect the most important tasks and to use the time in an efficient way, relates to the first problem: rush.

The great number of work tasks and occasional sick leaves were mentioned as reasons for hurry and for the need for prioritizing. In addition, the quality of communication was mentioned to be an issue, especially when tasks are left unfinished.

6.3 Problems Related to the Implementation of Corrective and Preventing Actions

Loviisa NPP has an extensive method for studying operational events, as required in YVL Guide A.10 (2013). In each report, corrective actions are proposed and they should be implemented. As already previously stated by Jaakkola (2013) the procedure is not fully functioning as it should, and similar events have been repeating. Jaakkola was studying reports on a plant scale, but the same pattern was also seen when focusing only on release related reports: A lot of time and effort is put into studying the reasons and consequences of an event and into proposing the corrective actions. The implementing of the corrective actions is not supervised in a similar level and is usually a responsibility of one person, whereas the previous steps in event study are performed by a group of people.

7 RECOMMENDATIONS

7.1 Sampling

The weakness in TZ80 was the long reaction time in a case of any deviations. The monitoring becomes easier if the sample collection tank can be monitored via process computer in the future. As an immediate action the readings on the screen could be manually checked more often by operating or laboratory personnel.

The weakness in TD/TR was the unmixed content of the tanks. The effect of mixing on the activity results is a possible research target that could be studied. The current method can be considered as conservative and as the studied concentrations are low, there is no guarantees that mixing tests without some added tracer nuclide would give reliable results. Using a tracer in this case is very problematic, as in addition to introducing an additional release to the environment, the tanks would be contaminated after the studies. One possible test method could be to simulate the tank filling and sampling in a smaller scale, for example in a laboratory.

TL00 has been the subject of many studies and the problems in the process are well identified. The finding of the right corrective actions is however difficult. Performing any kind of tests with an equipment that must be consistent with OLC is a challenge as the studies should not affect the required measurements.

7.3 Human Actions

The skill based errors were the dominant reason behind most of the human related event reports. It is important to pay attention to this fact: errors happen mostly in a known environment when performing a familiar task. The employees of the laboratory of radiochemistry mentioned the fast-paced environment and the amount of work to be reasons that make it more difficult to stay focused. The number of skill based errors can be decreased using good checklists and using cross-checking, where coworkers supervise each other’s work. It is also good to consider possible digital solutions to help to organize and prioritize the tasks. Even simple reminder alarms can be suitable in some cases: Similar to modern refrigerators that give an alarm noise, if the door is left open for a longer time period, a pump that should be turned on, could give an alarm if it is turned off for too long.

To avoid the knowledge based errors, it is a good practice to examine possible “what if” scenarios when preparing to a work. The plant has good general checklists to help with this, but it is also good to utilize the event reports from previous cases every now and then, so the previous learnings are not forgotten. It is also important to evaluate what are the “what ifs” unique to the considered case, apart from the general ones. The rule based errors have been rare and that indicates the instructions being good and kept up to date. It is also important to encourage the employees to keep their personal notes up to date.

Based on the anonymous survey on laboratory personnel, the employees are highly motivated and understand the importance of their work. As the power plant gets older the amount of work in the laboratory is expected to rise. This was worrying the employees, and they also estimated the number of unexpected situations, as surprising outages, to increase in the future. The increased work load can lead to future skill based errors and the unexpected situations to knowledge based errors. Also the retirement of older employees and disappearing knowhow were seen as concerns.

When the workload is increasing, the importance of the planning is emphasized. The feeling of constant hurry in the laboratory is a concerning phenomenon and this should be solved in a cooperation with the employees. To find the correct methods, it is important to collect feedback. The email survey is one way to collect feedback and the strength of the method is the fact that person can find the good time and a correct mindset to answer the questions. So called brainstorming session held during a meeting is also one way to collect feedback, but in this method there is always a risk that the voice of everyone is not heard. When feedback is collected, summarizing the results and discussing them with the employees is important. When something useful comes up, it should be implemented. If the feedback is not refined into actions, the motivation to give and receive feedback may decrease.

To get the full use out of the event reporting procedure, the implementation of the corrective and preventing actions should be improved. This problem should be noticed on a plant level as already recommended by Jaakkola (2013). The effectiveness of taken actions is also important to be evaluated later on and improved further if needed.

8 CONCLUSIONS

The objective of this study was to

- prepare process descriptions describing the main discharge processes
- to identify the weaknesses in these processes and
- to give recommendations in order to prevent further operational events.

The process descriptions for each discharge route were prepared using several existing process descriptions, PI-diagrams, and instructions. The identifying of the possible problems was mainly based on reports from previous operational events. In addition, the questions listed in Table I were used. In order to get more insights on human error and some processes, also interviews were used.

The main finding was that the events related to discharge processes have mainly been caused by so-called human error. When the errors where categorized into three commonly used categories, it was pointed out that the error distribution among the categories differed from the general distribution pattern in the nuclear industry.

Whereas in the nuclear industry the rule based errors are generally the most presented group, in Loviisa NPP over half of the events related to discharge processes were skill based, rule based errors being almost nonexistent. This indicates that the employees working with the discharge processes are highly trained, experienced and motivated and follow the rules, but the work is occasionally disturbed by different factors.

As a part of obtaining reliable discharge information, the sampling plays an important role. The integrity of the samples was preserved during and after sampling, but in the sampling itself, there was room for improvement.

The recommendations were given separately for sampling and human based problems. In order to detect possible anomalies in TZ80 process faster, the screen on sample collection tank should be monitored more often. Later, the data will be readable on process computer and the alarm light to be replaced with an alarm reaching the control room, as the automation system of the plant is renewed. The mixing of the control tanks TD/TR prior to sampling should be considered. The sampling equipment of C-14 and H-3 in TL00 process should be part of a regular inspection and maintenance procedure performed by properly trained person.

In order to reduce human related errors, the tasks should be clearly organized and prioritized in a cooperation with the employees. The work community should find the ways how to reduce the feeling of working in a hurry and to support each other to communicate better. It is very important to find a solution to this problem now, as in the future the amount of work is most likely to increase as the power plant is getting older. The already existing event report culture can help with this, if the reports are utilized more efficiently and more attention is paid on following the effects of the implemented actions.

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