Study on monitoring of radioactive discharges from nuclear facilities in the EU

Final report

Contract ENER/2021/NUCL/SI2.856940

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Acronyms

ASN	Nuclear Safety Authority, France (Autorité de Sûreté Nucléaire)
ANVS	The Authority for Nuclear Safety and Radiation Protection, The Netherlands
ASLAB	Czech Centre for the assessment of laboratories
BAT	Best Available Technique
BSR	The Nuclear Safety Requirements
BSS	Basic Safety Standards
BWR	Boiling Water Reactor
CANDU	Canadian Deuterium Uranium reactor
CNCAN	The National Commission for Nuclear Activities Control, Romania
The Consortium	The consortium formed by NucAdvisor, VTT and Nuvia CZ for conducting the "Study on monitoring of radioactive discharges from nuclear facilities in the EU"
DAC	Derived Air Concentration
DEL	Derived Emission Limits
EC	The European Commission
EC RADD or RADD	The European Commission RAdioactive Discharges Database for collecting, storing, exchanging and dissemination of information on radioactive discharges.
ECL	Environmental Control Laboratory
EPA	Environmental Protection Agency
EPR	European Pressurized water Reactor
EU	The European Union
Euratom	European Atomic Energy Community
FANC	The Belgium Federal Agency for Nuclear Control
HPGe	High Purity Germanium Detector
HT	Elemental tritium
HTO	Tritium oxide as water vapour
IAEA	International Atomic Energy Agency
Imfp	Radioiodine mixed fission products
INB	In French, "Installation Nucléaire de Base": each nuclear facility in France is referenced as an "INB" with a number.
INPP	Ignalina Nuclear Power Plant- Lithuania
IRE	Institute for radioelements- Belgium
IRSN	Institut de radioprotection et de sûreté nucléaire-France
ISO	International Organization for Standardization
KRT	The radiological monitoring system (EPR)
LO1&2	Loviisa units 1&2- Finland
LWGR	Light Water Graphite Reactor
MoH	The Ministry of Health
The MS	The Member States of the European Union

NF	Nuclear Facility
NI	Nuclear installation
NMP	National Monitoring Programme, Czech Republic
NPP	Nuclear Power Plant
NRG	Nuclear Research & consultancy Group in the Netherlands
OECD	Organisation for Economic Co-operation and Development
OL1,2,3	Olkiluoto units 1, 2, 3- Finland
OPR	the steady release rate based on the annual release rate
OPR	the steady release rate
PHA SR	Public Health Authority of Slovak Republic
PREDO	PREdication of Doses from normal releases of radionuclides to the environment
PWR	Pressurised Water Reactor
RBMK	Reaktor Bolšoi Moštšnosti Kanalnyi (High-Power Channel-Type Reactor)
Recommendation 2004/2/Euratom	Document "Commission recommendation of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation (notified under document number C(2003) 4832)- Noted "Recommendation 2004/2/Euratom" in this report. A Corrigendum to Commission Recommendation 2004/2/Euratom: on page 39, in the Annex, third column, the entry against 'Kr-85': for: '1E – 04', read: '1E + 04'.
RIVM	the National Institute for Public Health and the Environment, The Netherlands
SKI	the Swedish Nuclear Power Inspectorate
SMM	The Swedish Radiation Safety Authority
SRP	Significant Release Pathways
SSI	Swedish Radiation Protection Authority
STUK	The Finnish Radiation and Nuclear Safety Authority
SUJB	The State Office for Nuclear Safety
SUJB	The State Office for Nuclear Safety in the Czech Republic
TSO	Technical support organisation
TVO	Teollisuuden Voima Oy- Finland
VATESI	The State Nuclear Power Safety Inspectorate in Lithuania
VVER	Modified (including containment building and ice condenser) Russian designed pressurised water reactor
YVL	Regulatory guides on nuclear safety

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The Consortium has visited 11 nuclear facilities in the EU to study the monitoring of radioactive liquid/gaseous discharges. This study has been conducted in close cooperation with the nuclear facilities and Member State (MS) National Authorities. The Consortium thanks the European Commission and DG ENER, who supported the study during this time by providing advice and guidance.

The authors express their sincere gratitude to all the participants who provided extensive, reliable, and comprehensive information. The participants spent time filling questionnaires and provided a large set of data, allowing the Consortium to better understand the complexity of monitoring liquid and gaseous radioactive discharges from nuclear facilities.

The authors are also very grateful to all participants in the one-day workshop on March 1st, 2023, in Brussels, who gathered representatives from European National Authorities, the nuclear industry, and international organizations. The outcomes of the workshop have been incorporated in this report.

Abstract (English version)

Chapter three of Title II of the Euratom Treaty, Article 35 states: "Each Member State shall establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards".

This study focuses on the facilities that have the authorisation to discharge a significant amount of radioactivity in the environment. With this authorisation, the nuclear facilities are required to have technical systems in place to carry out continuous or batch-wise monitoring of these discharges.

During this study, eleven nuclear facilities in nine Member States (covering nuclear power plants with different technologies, a spent fuel reprocessing plant, medical isotope production facilities, and a nuclear plant under dismantling) were visited for a detailed assessment of the monitoring of liquid and gaseous radioactive discharge systems. A detailed technical description outlining the monitoring arrangement for each facility is given in a separate document (Facility Reports).

This report provides an overview of the best practices, and underlines suggestions for further development. This report also evaluates the EU countries' annual reporting discharges regarding Recommendation 2004/2/Euratom on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation.

After a technical assessment of the control and monitoring systems of the liquid and gaseous discharges, the control/monitoring systems were found to be very high quality, while the equipment and laboratories are run by trained and experienced personnel. The study has concluded that the national regulatory framework is adequate, and professionally implemented by licensees while under the Nuclear Safety Authority's scrutiny. The measurement results are subject to international intercomparison as a guarantee of quality.

Abstract (Version Française)

Le chapitre 3 du titre II du traité Euratom, Article 35 précise que « Chaque État Membre établit les installations nécessaires pour effectuer le contrôle permanent du taux de la radioactivité de l'atmosphère, des eaux et du sol ainsi que le contrôle du respect des normes de base ».

Cette étude analyse plusieurs installations nucléaires qui ont une autorisation de rejets radioactifs liquides et gazeux de radioactivité dans l’environnement et sont dans l’obligation de mettre en place les moyens de mesure et de contrôle permanents ou par prélèvements de la radioactivité rejetée.

Lors de cette étude, onze installations nucléaires (couvrant des centrales nucléaires de puissance de différentes technologies, une installation de retraitement du combustible nucléaire usé, des installations de production d’isotopes médicaux et une centrale nucléaire en démantèlement) situées dans neuf États Membres ont été visitées pour conduire une analyse détaillée des systèmes de mesures et de contrôle des rejets radioactifs liquides et gazeux. Les rapports détaillés sur chacune des installations visitées sont donnés dans des documents séparés.

Le rapport souligne les bonnes pratiques d’exploitation et fait des propositions pour des développements futurs. Le rapport analyse également la mise en œuvre de la recommandation 2004/2 Euratom, sur les informations normalisées sur les rejets radioactifs gazeux et liquides dans l'environnement des réacteurs nucléaires de puissance et des usines de retraitement du combustible en fonctionnement normal, édictée par la Commission Européenne.

Suite à l’analyse technique des systèmes de mesure et de contrôle des rejets radioactifs liquides et gazeux dans ces installations, il est acté de la haute qualité de ces systèmes de mesure et contrôle, mis en œuvre par des opérateurs formés et expérimentés. Les conclusions de l’étude montrent également que le cadre réglementaire est adapté, il est mis en œuvre professionnellement par les exploitants nucléaires et fait l’objet de contrôles et vérifications réguliers du régulateur. Les méthodes et résultats des mesures des installations nucléaires font l’objet d’inter-comparaisons internationales, gage de qualité.

Executive Summary (English version)

The operation of nuclear facilities results in the discharge of radioactivity to the surrounding environment in both liquid and gaseous forms. Nuclear facility operators are required to control the amount of radioactivity released, assess the liquid/gaseous discharges by the limits imposed by the National Authorities, and report them.

Chapter three of Title II of the Euratom Treaty (Health and Safety), Article 35 states: "Each Member State shall establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards. The Commission shall have the right of access to such facilities; it may verify their operation and efficiency". The European Commission is responsible for verifications under the terms of Article 35 of the Euratom Treaty.

Moreover, Article 36 of the Euratom Treaty requires that "the appropriate authorities shall periodically communicate information on the checks referred to in Article 35 to the Commission so that it is kept informed of the level of radioactivity to which the public is exposed". Commission Recommendation 2004/2/Euratom provides a guide for the Members States on reporting radionuclides released from nuclear power reactors and reprocessing plants in normal operation. Data reported by the Member States (MS) are compiled in the Commission's Radioactive Discharges Database (RADD).

This study focuses on the facilities that have the authorisation to discharge a significant amount of radioactivity into the environment and are required under Article 35 to have technical systems in place to preform either continuous or batch-wise monitoring of liquid/gaseous discharges.

Over 14 months (years 2022-2023), the Consortium visited 11 Nuclear facilities in the EU to review and discuss the control and monitoring of liquid and gaseous radioactive discharges with nuclear facilities operators and their National Authorities.

The 11 facilities in Europe covered by this study are not restricted to the specific facility types covered by the provisions of Recommendation 2004/2/Euratom, which mainly applies to nuclear power plants and reprocessing facilities. This study also includes medical isotope production facilities and a nuclear plant in decommissioning (see the complete list of facilities in the table below).

Table 1: List of nuclear facilities included in the study

Country	Facility
France	La Hague (Nuclear spent fuel reprocessing plant) Flamanville 3 NPP (Power production / EPR plant)
Finland	Olkiluoto 3 NPP (Power production / EPR plant) Loviisa (Power production / VVER power plant)
Czech Republic	Temelin NPP (Power production / VVER 1000 plant)
Slovak Republic	Mochovce NPP (Power production / VVER 440 plant)
Sweden	Forsmark NPP (Power production / BWR plant)
Belgium	IRE (Medical Isotope production)
Lithuania	Ignalina NPP (NPP in decommissioning / RBMK plant)
Netherlands	Petten (Medical Isotope production)
Romania	Cernavoda NPP (Power production / CANDU plant)

The liquid/gaseous discharges that result from operation may contain a range of radioactive isotopes, which may have a significant impact on public health and the environment. The following isotopes are commonly found in radioactive discharges:

- **Tritium:** A radioactive isotope of hydrogen which can be present in both liquid and gaseous discharges from nuclear facilities. It is a significant concern because it can combine with oxygen to form tritiated water, which is easily absorbed by living organisms, and has a long half-life (12.3 years).
- **Carbon 14:** A radioactive isotope that can be present in both liquid and gaseous forms. It is concerning because it can accumulate in living organisms and cause damage to DNA and has a long half-life (5730 years).
- **Iodine:** Radioactive iodine isotopes, such as iodine-131, are often released into the environment as gaseous discharges. These isotopes can accumulate in the thyroid gland and increase the risk of thyroid cancer.
- **Noble gases:** Xenon and krypton are two of the most common gases released in discharges from nuclear facilities. These isotopes are concerning because they can travel long distances and impact public health and the environment far from the source of the discharge.
- **Other fission products:** Other fission products created during the nuclear fission process.
- **Activation products:** Isotopes created when materials in the nuclear reactor undergo neutron activation by capture.

Fission and activation products can be present in both liquid and gaseous discharges and can have a range of health and environmental impacts.

Effective monitoring and control of discharge is essential for ensuring the safe operation of nuclear facilities and minimizing the impact on the environment and public health.

The outcomes of the study are organised around five main topics:

1. Implementation of the periodical discharge limit review to ensure the discharge limits are still "fit for purpose";
2. Analysing the performance and the means of prevention and reduction of impacts by the nuclear installation, considering the best available techniques;
3. Benchmarking between nuclear facilities;
4. Providing limits that are radionuclide-specific in national regulation;
5. The relevance of Recommendation 2004/2/Euratom and topics for further development of the EU-level guidance in this area.

The workshop held on March 1st of 2023 in Brussels, gathered all stakeholders involved in this study, with the addition of the European Commission and the Consortium. The 35 experts, representing the National Authorities (Belgium, Finland, France, Italy, Lithuania, The Netherlands, Romania, Slovakia, Sweden, Spain) and nuclear facility operators, discussed the study results on the five main topics and the conclusions to be agreed upon.

Based on these conclusions, the Consortium has elaborated on three recommendations, one comment, and the analysis on the relevance of Recommendation 2004/2/Euratom.

Recommendation n°1

It is recommended that Nuclear Regulators implement a periodical discharge limit review to ensure they are still ''fit for purpose"

It is important to periodically re-evaluate discharge limits to ensure they remain "fit for purpose". Currently, the discharge limit review procedures vary in the MS; some countries conduct regular reviews to confirm the appropriateness of set limits, other countries establish fixed limits for the entire license duration. In addition, it was observed that some regulators set reference values corresponding to an expected release based on previous years' data, and every five years the operator establishes goal values (equal to or smaller than the reference values), which are the annual target to reach in terms of releases.

The periodic review of discharge limits for radioactive substances from nuclear facilities is important for various reasons. It helps protect the environment by ensuring that released radioactive substances remain within safe levels, safeguarding ecosystems and human health. Regular reviews ensure compliance with regulations and allow for the incorporation of technological advancements, enhancing the monitoring and treatment of radioactive substances. By identifying potential risks and implementing mitigation measures, the review process promotes the safety and security of nuclear facilities.

Recommendation n°2

It is recommended that the operator should periodically analyse the performance, the means of prevention, and reduction of impacts by the nuclear installation, considering the best available techniques; and periodically assess training and qualification of operators involved in the chain of monitoring control and measures of radioactive liquid/gaseous discharges.

The safe operation of nuclear facilities is of paramount importance, and operators are required to regularly assess their performance and means of preventing and reducing the impact of nuclear installations, utilising the best available techniques. The effective monitoring of radioactive liquid/gaseous discharges, a critical aspect of this assessment, requires using the most advanced monitoring technologies and techniques to minimise the impact on the environment and public health. It is also important to pay attention to the training and appropriate qualifications of personnel involved in the chain of control and monitoring of radioactive discharges (operating procedures for laboratories, samples, etc.).

Recommendation n°3

It is recommended that periodic benchmarking, involving same type and technology, of nuclear facilities be pursued and encouraged with the sharing of best practices between operators in mind.

Currently, some nuclear facilities of the study regularly participate in comparison programs with facilities that have similar technology, at a national and/or international level. Nevertheless, it is recommended to create a framework for benchmarking to accurately define the intercomparison programs for nuclear facilities of the same type. The framework should be developed in collaboration with the relevant stakeholders where appropriate, be based on the nuclear facility technology, and include nuclear facility operators, regulators, and other experts.

The benchmarking framework should focus on better understanding the hypotheses made when calculating the radioactive discharges and outline key performance indicators.

Keep in mind that the intercomparison programs' objective is not to rank performances between nuclear installations but rather to identify best practices to be shared among the participants and implemented as appropriate for self-improvement.

Comment n°1 The radioactive discharge limits should be specified by the National regulators.

The study identified four possible methods for the regulator to express discharge limits:

1) Limits expressed as rates of individual or grouped radionuclides, typically in terabecquerels per year (TBq/year).
2) Limits expressed as concentrations, typically in becquerels per cubic meter (Bq/m^3).
3) Limits expressed in terms of the dose to a critical group or a representative person(mSv/year).
4) Limits expressed in a manner that accounts for the radiological significance of different radionuclides (Re).

The third and fourth methods are aligned with the overarching objective of discharge limits, which is to minimize the radiological impact on the population. However, they have several limitations, in example, relying on dispersion, human habits, and environmental models, having a lack of nuclide-specificity and transparency.

Alternatively, the fourth method uses a formula for limitation that considers the radiological significance of different radionuclides. However, this method also may lack transparency and may require additional time before any potential breach of authorization can be detected. In addition, both the third and fourth methods could result in a more generous release rate for certain radionuclides than is justifiable.

The Consortium acknowledges the fact that these differences on how to express discharge limits are the result of a long historical process deeply analysed by regulators and experts. Changing from one method to another is a lengthy process which would involve many stakeholders. Requiring through a European regulation to implementing changes in this area may be source of disputes for some Member States.

The Consortium mentions that the use of the first method which entails individual radionuclide discharge rates (e.g., TBq/y) limits is considered as a best practice for all nuclear facilities, as it is more transparent, nuclide-specific, and less likely to result in a more generous release rate for certain radionuclides than is justified.

Analysis of the relevance of Recommendation 2004/2/Euratom

On the topic of relevance of Recommendation 2004/2/Euratom, both nuclear facility operators and National Authorities have offered their perspectives on its applicability. Most National Authorities reported no major difficulties in integrating Recommendation 2004/2/Euratom into their national requirements, with the addition of most nuclear operators confirming that it remains relevant. However, it is worth noting that Recommendation 2004/2/Euratom, which concerns the standardisation of information on airborne and liquid radioactive discharges into the environment, is almost two decades old, having entered into force on 6th January 2004.

At this time, some of the reference documents cited therein have since been cancelled, superseded, or repealed:

- Article 124 of the Euratom Treaty regarding institutional and financial provisions was repealed.
- Commission Recommendation 2010/635/Euratom has replaced 1999/829/Euratom.
- Council Directive 2013/59/Euratom on Basic Safety Standards has replaced 96/29/Euratom.
- ISO[1] 11929-1:2019 3, ISO 11929-2:2019, ISO 11929-3:2019, and ISO 11929-4:2020 have superseded ISO/IS 11929-7.

In addition, it is noted that nuclear facilities such as medical isotope production facilities and nuclear power plants under the dismantling phase are not formally included in this Recommendation. However, among the 11 nuclear facilities visited, we note that in Belgium, National Safety Authority (FANC), requires the "Institut des RadioÉléments" (IRE) to report liquid and gaseous radionuclides discharged in a similar format as Recommendation 2004/2/Euratom.

It is noted as well that some nuclear plants in the European Union are in dismantling phases and proceed to discharge radioactive liquid and gaseous effluents. Currently, Recommendation 2004/2/Euratom does not require Nuclear Power Plants under dismantling phase to report to the RADD.

Noting that in the European Union nuclear power plants in dismantling phases will be more in the coming decades, it is suggested that the European Commission analyses the appropriate way of reporting on the radioactive liquid and gaseous releases during that phase.

Although Romania joined the European Union in 2007, after publication of Recommendation 2004/2/Euratom (which did not consider the PHWR "CANDU" reactor technology), the Romanian National Authority and nuclear operator consider Recommendation appropriate for CANDU as all the key nuclides related to this reactor technology are included in the Annexes of Recommendation 2004/2/Euratom.

It is suggested that the annual production of nuclear power plants be specified when reporting discharges. Additionally, it is advisable that a graph function be

[1] ISO 11929 specifies a procedure related to the measurement of the ionising radiation for the calculation of the "decision threshold", the "detection limit". This standard has been split in four parts.

added to the RADD database to facilitate the identification of trends, which would enhance its usability and appeal.

These points above, related to Recommendation 2004/2/Euratom, have been discussed during the workshop (March 1st, 2023). As per the input received from the nuclear operators and their National Authorities, they determined that the extension of Recommendation 2004/2/Euratom may not be relevant due to the diversity of nuclear facilities and the associated exemptions that may arise. The National Authorities and Nuclear operators are not inclined to support an expansion of Recommendation's scope and believe that there is currently no need for further development of EU-level guidance in this area.

Résumé exécutif (Version en français)

L'exploitation des installations nucléaires rejette des effluents radioactifs dans l'environnement proche, sous forme liquide et gazeux. Les exploitants sont tenus de contrôler la quantité de radioactivité relâchée dans l'environnement de manière continue, et de comparer ces rejets au regard des limites imposées par les autorités de sûreté nationales et d'en faire un bilan mis à la disposition de ces mêmes autorités.

Le chapitre 3 du Titre II du Traité EURATOM (Santé et Sureté), Article 35 demande que « Chaque État Membre établit les installations nécessaires pour effectuer le contrôle permanent du taux de la radioactivité de l'atmosphère, des eaux et du sol ainsi que le contrôle du respect des normes de base ». La Commission Européenne a le droit d'accéder aux installations nucléaires afin de vérifier la mise en œuvre de la qualité et de l'efficacité des installations. La Commission Européenne met en œuvre ces vérifications en référence à l'article 35 du Traité EURATOM

De plus, l'article 36 du Traité EURATOM stipule que les autorités nationales concernées, communiquent régulièrement à la Commission Européenne, les informations sur les contrôles de l'Environnement mis en œuvre au titre de l'article 35 afin de connaitre le niveau de radioactivité auquel le public est exposé. La recommandation de la Commission Européenne 2004/2/Euratom fournit aux États Membres un guide pour établir le rapport d'informations attendues sur les radionucléides rejetés par les réacteurs de puissance et les installations de retraitement du combustible usé. Les informations compilées sont ainsi mises à disposition par les États Membres dans la base de données des rejets radioactifs (RADD).

L'étude réalisée s'est concentrée sur les installations nucléaires ayant une autorisation de rejets dans l'environnement d'un niveau significatif et qui sont donc tenus au titre de l'article 35 de disposer des installations techniques pour contrôler et mesurer en continu ou par prélèvements les rejets.

Durant ces 14 mois, sur les années 2022 et 2023, le Consortium a visité 11 installations nucléaires dans l'Union Européenne pour analyser et discuter avec les exploitants nucléaire et leurs autorités de Sureté Nucléaire, le dossier des rejets radioactifs liquides et gazeux, leurs mesures et leurs contrôles.

Les 11 installations nucléaires concernées par cette étude couvrent celles de la recommandation 2004/2/EURATOM et au-delà, car des installations de production d'isotopes médicaux et une centrale en démantèlement ont été incluses dans l'étude.

Liste des installations nucléaires incluses dans l'étude :

Pays	Installations nucléaires
France	La Hague (Installation de retraitement du combustible usé) Flamanville 3 (Réacteur de puissance de type EPR)
Finlande	Olkiluoto 3 (Réacteur de puissance de type EPR) Loviisa (Réacteur de puissance de type VVER 440)
Republique Tchèque	Temelin (Réacteur de puissance de type VVER 1000)
République Slovaque	Mochovce (Centrale nucléaire de puissance de type VVER 440)
Suède	Forsmark (Réacteur de puissance de type BWR)
Belgique	IRE (Institut des RadioÉléments – Production d'isotopes médicaux)
Lithuanie	Ignalina (Centrale Nucléaire en démantèlement de type RBMK)
Les Pays Bas	Petten HFR (Production d'isotopes médicaux)
Roumanie	Cernavoda (Centrale nucléaire de puissance de type CANDU)

Les rejets radioactifs des installations nucléaires peuvent prendre différentes formes: liquide et gazeuse. Les isotopes suivants sont habituellement mesurés dans les rejets radioactifs :

- **Le tritium:** isotope de l'hydrogène qui peut être présent sous forme liquide et gazeux. Il requiert une attention particulière car il peut se combiner avec de l'oxygène et former de l'eau tritiée facilement absorbée par les organismes vivants, avec une période de 12,3 années.
- **Le carbone 14:** isotope radioactif rejeté également sous forme liquide ou gazeuse. Il requiert une attention particulière car il s'accumule dans les organismes vivants et cause des dommages sur l'ADN et a une période de 5730 années.
- **Les iodes:** Plusieurs isotopes radioactifs de l'Iode, comme l'Iode-131 (qui sont souvent rejetés sous forme gazeuse). Ces isotopes s'accumulent dans la glande thyroïdienne et accroissent le risque de cancers thyroïdiens
- **Les gaz nobles:** le Xénon and le Krypton sont les deux gaz nobles les plus communément rejetés sous forme gazeuse. Ces isotopes ont un pouvoir de dispersion sur de longues distances et un impact potentiel sur la santé et l'environnement
- **Autres produits de fission:** nombreux isotopes créés lors du processus de fission, présents sous forme liquide et gazeux.
- **Les produits d'activation:** isotopes créés dans les matériaux des installations sous l'effet de réactions nucléaires de captures de neutrons

Les produits de fission et d'activation sont présents sous forme liquide et gazeuse dans les rejets et peuvent avoir un large impact sur la santé et l'environnement.

La mesure et le contrôle de ces différentes formes de rejets sont essentiels pour respecter un fonctionnement en toute sûreté des installations nucléaires afin de minimiser l'impact sur l'environnement et la santé du public.

Les conclusions de l'étude sont organisées autour de cinq thèmes

1. La mise en œuvre d'une revue périodiques pour vérifier que les limites réglementaires ne nécessitent pas une nouvelle évaluation
2. L'analyse de l'efficacité des moyens de prévention et de réduction des impacts des installations nucléaires, avec une mise en œuvre des meilleures techniques disponibles
3. Les inter-comparaisons des rejets entre les différentes installations nucléaires
4. La définition des limites réglementaires basées sur les radionucléides rejetés
5. La pertinence de la Recommandation de la Commission Européenne 2004/2/EURATOM et la définition de nouvelles actions sous l'impulsion de la Commission Européenne dans le domaine de la mesure et du contrôle des rejets radioactifs

Le séminaire de travail organisé le 1er mars 2023 à Bruxelles a réuni autour de la Commission Européenne et du Consortium, toutes les parties prenantes ayant participé à l'étude. Les 35 experts, représentant les autorités de sureté nationales (Belgique, Espagne, Finlande, France, Italie, Lituanie, Les Pays Bas, Roumanie, Slovaquie) et les exploitants des installations nucléaires, ont débattu des résultats de l'étude autour des cinq thèmes ci-dessus, et des conclusions à retenir.

C'est sur la base de ces conclusions, que le Consortium, a élaboré en synthèse, trois recommandations, un commentaire et une analyse de la pertinence de la Recommandation de la Commission Européenne 2004/2/EURATOM.

Recommandation n°1

Il est recommandé que les Autorités de Sûreté mettent en œuvre une revue périodique des limites de rejets afin de s'assurer que ces limites sont toujours adaptées.

Il est important de réévaluer périodiquement les limite de rejets afin de s'assurer qu'elles sont toujours adaptées. Actuellement, la méthode de réévaluation des limites diffère d'un Etat Membre à l'autre ; certains pays mettent en œuvre des réévaluations périodiques pour vérifier et confirmer les valeurs limites, d'autre pays établissent des valeurs limites fixées pour toute la durée d'autorisation d'exploitation. De plus il faut noter que certaines autorités nationales établissent des valeurs limites de rejets de référence basées sur les mesures annuelles antérieures et tous les 5 ans les exploitants établissent des valeurs limites considérées comme les valeurs annuelles cibles de référence

Une revue périodique des limites des rejets radioactifs des installations nucléaires est importante pour plusieurs raisons. Cela permet de s'assurer que les limites de protection de l'environnement et de l'écosystème restent adaptées. Des revues périodiques de ces limites permettent aussi d'inclure les évolutions et améliorations des techniques de contrôle et de mesure des rejets radioactifs. En identifiant les risques et en mettant en œuvre des parades, cette revue périodique participe à l'amélioration continue de la sûreté des installations nucléaires

Recommandation n°2

Il est recommandé que les exploitants nucléaires, périodiquement, analysent l'efficacité des moyens de prévention et de réduction des rejets radioactifs de leurs installations, prenant en compte les meilleures techniques disponibles et périodiquement, évaluent la formation et la qualification des personnels impliqués dans la chaine des contrôles et des mesures des rejets.

L'exploitation en toute sûreté des installations nucléaires, notamment le contrôle et la mesure des rejets radioactifs est d'une importance capitale pour l'industrie nucléaire. Dans ce cadre la recherche de l'utilisation des meilleures techniques disponibles, tant pour la prévention que pour la mesure et le contrôle des rejets radioactifs est un élément de l'excellence opérationnelle. Il est essentiel également de veiller à la formation et à la haute qualification des personnels impliqués dans la chaine de contrôle et de mesures des rejets radioactifs et les procédures mises en œuvre dans les laboratoires et le prélèvement des échantillons.

Recommandation n°3

Il est recommandé que des inter-comparaisons entre des installations nucléaires de même type ou technologie soient faites et encouragées, avec un objectif de partage des bonnes pratiques entre exploitants.

Actuellement, certaines installations nucléaires de l'étude, participent régulièrement à des inter-comparaisons avec des d'autres installations de même technologie, soit au niveau national ou international. Néanmoins, il est recommandé de mieux définir les conditions et les hypothèses de ces inter-comparaisons entre installations de même technologie.

il est important que le cadre de ces inter comparaisons soit mieux élaboré ente les différentes parties prenantes, basé sur la similitude de la technologie de contrôle et de mesure des rejets radioactifs, les méthodes et procédures utilisées par les exploitants, et y inclure la participation des régulateurs et des experts.

Le cadre de ces inter comparaisons doit bien définir les indicateurs clés de l'exploitation qui feront l'objets des comparaisons.

L'objectif n'est pas de classer les exploitants entre eux mais plutôt d'identifier et partager les meilleurs pratiques et les mettre en œuvre pour une auto-amélioration des méthodes de contrôle et de mesure des rejets radioactifs.

Commentaire sur les limites des rejets radioactifs spécifiés par les autorités nationales

L'étude a identifié quatre méthodes fixant les limites des rejets radioactifs telles que définies par le régulateur :

1) Limites fixées comme une quantité de radio-isotopes individuels ou groupés, exprimées en térabecquerels par an (TBq/an).
2) Limites fixées en termes de concentrations, typiquement en becquerels par mètre cube (Bq/m^3).
3) Limites exprimées en dose reçue par un groupe de population représentatif.
4) Limites exprimées en termes d'importance radiologique de différents isotopes.

La troisième et quatrième méthodes ont l'objectif global de fixer des limites de rejets radioactifs en référence à l'impact radiologique sur les populations. Cependant, ceci présente plusieurs biais, comme la dispersion des rejets, les habitudes de vie et les modélisations liées à l'environnement. De plus il n'y a pas de référence aux isotopes considérés.

Quelquefois la quatrième méthode utilise une formulation qui minimise l'importance radiologique des différents isotopes rejetés. Cette méthode peut aussi manquer de transparence et peut conduire à retarder la détection de franchissement des limites. Les deux méthodes, la troisième et la quatrième, peuvent conduire à des rejets plus importants de certains isotopes sans que cela se justifie.

Le Consortium prend acte que ces différentes méthodes dans la fixation des limites des rejets radioactifs, sont le résultat d'un long processus historique qui a été particulièrement analysé et approfondi au sein des autorités et experts nationaux avant décision. Changer de méthode serait un long processus impliquant de nombreuses parties prenantes. Imposer, par une réglementation européenne, de mettre en œuvre un tel changement serait source de litige au sein des États Membres.

L'avis du Consortium est que la première méthode qui fixe des limites de rejets radioactifs pour chaque isotope (e.g TBq/y), est celle qui relève d'une bonne pratique applicable à toutes les installations nucléaires, elle est transparente et permet de comptabiliser tous les isotopes rejetés, sans donner plus d'importance aux différents isotopes quant à leur impact radiologique.

Analyse de la pertinence de la Recommandation 2004/2/Euratom de la Commission Européenne.

La pertinence de cette recommandation a été particulièrement discutée par les régulateurs nationaux et les exploitants des installations nucléaire durant l'étude et le séminaire de travail des experts. De nombreux régulateurs ont souligné que la mise en œuvre de cette recommandation ne posait pas de difficultés majeures pour l'intégrer dans les textes réglementaires en vigueur dans leur pays. Les exploitants ont confirmé que le contenu technique de la recommandation est tout à fait adapté à leurs pratiques du contrôle et des mesures des rejets radioactifs. Cependant, il faut souligner que cette recommandation qui standardise l'information annuelle transmise par chaque État Membre à la Commission sur la quantité d'isotopes rejetés dans l'air et dans le milieu aquatique, a été émise il y près de 20 ans et pourrait donc être l'objet d'un retour d'expérience.

En particulier plusieurs documents cités en référence ont été annulés, remplacés ou abrogés. On citera :

- L'article 124 du traité Euratom qui a été abrogé.
- La recommandation de la Commission 2010/635/Euratom, qui a remplacé la 1999/829/Euratom
- La Directive du Conseil 2013/59/Euratom sur les normes de base de la sureté, qui a remplacé la Directive 96/29/Euratom.
- Plusieurs normes ISO[2] : ISO 11929-1-2019, ISO 11929-2-2019, ISO 11929-3-2019, and ISO 11929-4-2020, qui ont remplacé la norme ISO/IS 11929-7.

On note également que les installations nucléaires telles que celles produisant des isotopes médicaux et les centrales en démantèlement ne sont formellement pas incluses dans cette recommandation. Cependant parmi les onze installations visitées, on note qu'en Belgique, le Régulateur National (FANC) demande que «l'Institut des RadioÉléments» (IRE) publie le rapport sur ses rejets radioactifs liquides et gazeux dans un format similaire à celui de la Recommandation 2004/2/Euratom.

On note aussi que quelques centrales dans l'Union Européenne sont à différentes phases de démantèlement et procèdent à des rejets radioactifs liquides et gazeux. Actuellement, la Recommandation 2004/2/Euratom ne demande pas aux centrales en démantèlement de fournir un rapport compilé sur ces rejets dans RADD.

Dans l'Union Européenne, dans les prochaines décennies, le nombre de centrales en démantèlement va croitre. Il est suggéré que la Commission Européenne analyse la pertinence d'étendre le périmètre de la Recommandation

[2] La norme ISO 11929 spécifie une procédure applicable dans le domaine de la métrologie des rayonnements ionisants, pour le calcul du « seuil de décision » et de la « limite de détection ». Cette norme a été scindée en quatre parties.

2004/2/Euratom en analysant les spécificités des radionucléides rejetés, propres aux centrales en démantèlement

Même si la Roumanie a rejoint l'Union Européenne en 2007, après la publication de la Recommandation 2004/2/Euratom qui ne faisait donc pas référence aux réacteurs de technologie PHWR(CANDU), le régulateur et l'exploitant nucléaires roumains considèrent que cette recommandation est adaptée, soulignant que la quasi-totalité des isotopes rejetés par les réacteurs CANDU sont inclus dans les annexes de la recommandation.

Il est suggéré que l'énergie produite annuellement par chaque réacteur soit spécifiée dans le rapport de chaque État Membre. De plus, il est conseillé d'ajouter dans la base de données RADD, une fonction graphique pour faciliter la visualisation des variations et tendances des rejets radioactifs d'une année sur l'autre.

Les points ci-dessus, relatifs à la recommandation 2004/2/Euratom ont été discutés pendant le séminaire du 1er Mars 2023. Les commentaires faits par les différentes parties prenantes, régulateurs et opérateurs, montrent qu'il n'y a pas de justification de mettre à jour et/ou d'étendre le contenu de la Recommandation 2004/2/Euratom en raison de la grande diversité des installations nucléaires et des nombreux cas particuliers qu'il faudrait préciser. Toutes les parties prenantes ne sont donc pas favorables à une proposition de mise à jour de la recommandation 2004/2/Euratom.

1. Introduction

This study is focused on nuclear facilities authorized to discharge a significant amount of radioactivity into the environment, which are required under Article 35 to have suitable technical systems in place to monitor (continuous or batch-wise) liquid/gaseous discharges. The Consortium conducted on-site visits to 11 nuclear facilities across nine Member States over a period of 14 months, with the aim of reviewing and discussing controlling and monitoring liquid and gaseous radioactive discharges with Nuclear Facilities Operators and their Nuclear Safety Authorities. Additionally, the regulatory framework governing the control of radioactive discharges was comprehensively reviewed.

This report presents a comprehensive description of the situation in each Member State, including the regulatory basis for controls on radioactive discharges, discharge limits in force, reporting obligations, compulsory technical requirements, main strengths and weaknesses of monitoring radioactive discharges, and compliance with Recommendation 2004/2/Euratom. The countries under consideration in this study include France, Belgium, The Netherlands, Sweden, Finland, Lithuania, the Czech Republic, Slovak Republic, and Romania (Sections 2 through 10).

The primary objective of this study is to contribute to the effective implementation of the Euratom Treaty by identifying and analysing the current practices of radioactive discharge monitoring and control in the Member States. The Consortium consisted of experts from fields such as nuclear safety, radiation protection, and environmental monitoring, conducted thorough on-site visits, interviews, gathered the data, and received insights from various stakeholders involved in the control and monitoring of radioactive discharges.

In addition to the on-site visits and interviews, a one-day workshop was organized in Brussels as part of the study. The workshop brought together relevant authorities from the Member States to share national experiences and best practices regarding radioactive discharge monitoring and control. The aim of the workshop was to present the findings and recognise successful practices that could be adopted by other Member States. The workshop served as an important platform for collaboration and knowledge sharing among stakeholders involved in nuclear safety, radiation protection, and environmental monitoring. The insights gathered from the workshop further contributed to the overall findings and recommendations of this study.

The results of this study provide a comprehensive overview of the regulatory landscape and technical practices in the examined Member States. These findings were utilized to identify best practices and areas for improvement in radioactive discharge monitoring and control. Furthermore, the information gathered can serve as a valuable resource for policymakers, National Authorities, and operators in the nuclear sector. A detailed technical description outlining the monitoring arrangement for each facility is given in a separate document (Facility Reports).

Overall, this study represents a step towards strengthening the EU's approach to radioactive discharge monitoring and control. It demonstrates the EU's commitment to ensuring a high level of nuclear safety and environmental protection for its citizens.

1.1. State of the Art Equipment and Best Practices

With advancements in technology, it is important to keep up to date with the latest state of the art techniques and best practices for discharge monitoring technology. In this study, the Consortium visited 11 nuclear facilities and evaluated their discharge monitoring systems. It was found that the discharge monitoring system at Olkiluoto 3 was designed according to the best available technique (BAT) of the time. Based on our findings, the state-of-the-art equipment and best practices for discharge monitoring technology are highlighted.

State of the art equipment and best practices:

1. Off-line monitoring of gaseous effluents:
   The state-of-the-art technology for off-line monitoring of gaseous effluents is done by the Mirion PIS2 SC Serie F device. This all-in-one device allows for the collection of iodine's on an activated charcoal cartridge, aerosols on a Whatman Glass microfibre filter without a binder, and sampling of noble gases with grade GF/C and gas Marinelli. The sampling systems have two trains for redundancy, and the sampling frequency is weekly. After sampling, filters and cartridges are sent to the laboratory for nuclide-specific activity measurements.

2. H-3 and C-14 sampling:
   State of the art methods used for H-3 and C-14 sampling distinguish between organic and inorganic forms and are done in the nuclear facility's laboratory department. The best examples come from the synthetic zeolite 13X and Na-Al silicate samplers. The first molecular sieve collects inorganic forms of H-3 and C-14. After this, the sample flow is fed into a catalyst furnace at 450°C where organic C-14 and H-3 are transformed to CO2 and H2O. The benefit of sampling inorganic and organic forms separately is that the discharge amounts of H-3 and C-14 forms can be based on measurements instead of estimating the amount of inorganic form. When measurements are done within the nuclear facility's laboratory department, the time to obtain the results is shorter than when the measurements are subcontracted outside the nuclear facility. H-3 and C-14 samples are measured by high-performance liquid scintillation counters.

3. Gamma spectrometry:
   State of the art gamma spectrometry is done with HPGe detectors that use electrical cooling. The germanium crystal used in the device has a relatively low band gap, and it needs to be cooled to reduce the thermal generation of charge carriers. The most common cooling method is liquid nitrogen, but irregular detector-filling, unreliable liquid nitrogen supplies, and security related to nitrogen handling can be problems.

4. On-line monitoring of gaseous effluents:
   On-line monitoring of gaseous effluents seems best done by the Mirion PING206S device. This device continuously measures the discharges of aerosols, iodine's, and noble gases' volumetric activity in stacks. The device is a combination of three different devices where the IM 201S measures the volumetric gamma activity of the radioactive iodine sample, NGM 204S monitors noble gases at low levels with dynamic gamma and pressure compensation (dual large-area silicon), and ABPM 20S monitors samples filtered from air and allows dynamic compensation of radon. Noble gases by nuclide are monitored with a separate detector in an 18.3 litres chamber at the sampling flow rate of 1.4 m3/h.

5. On-line monitoring in the evacuation pipe to measure the volumetric activity during the discharge.
   Such arrangements enable continuous monitoring of liquid discharge and provide the possibility of continuous collection of representative samples. Continuous monitoring of the activity in the evacuation piping can also be displayed and recorded permanently. Additionally, if the radioactivity exceeds pre-set limits, the evacuation valve can be closed immediately to prevent further discharges. This technology ensures that the monitoring process is reliable, accurate, and efficient, while also minimizing the risk of exceeding the discharge limits.

6. Measuring the volumetric gamma activity of radioactive iodine in both inorganic and organic forms.

   Measuring iodine separately in its organic and inorganic forms is beneficial as it allows for a better uncertainty estimation. Organic and inorganic forms of iodine have different physical and chemical properties; thus they behave differently in the environment. Measuring them separately can help determine the sources and pathways of iodine releases and assess the effectiveness of control measures. In addition, the regulatory limits for discharge of radioactive iodine are often specified separately for organic and inorganic forms, and accurate measurements of each form are necessary to ensure compliance with these limits. Therefore, measuring iodine separately in organic and inorganic forms can provide more accurate and reliable data for regulatory compliance and environmental protection.

7. Sampling directly from the stack instead of from a bypass.

Measuring flow in stacks and bypass can represent a source of uncertainty. By sampling directly from the stack, the uncertainty is lower than when sampling from a bypass. Measuring straight from the stack also helps to ensure that representative samples are collected, which contributes to reliable and accurate measurements.

1.2. Reasons causing uncertainty in the monitoring results.

There are various factors introducing uncertainties in the discharge monitoring results. During the workshop, this subject was addressed through a series of statements discussing the uncertainties associated with measurements/ calculations derived from a study. Specifically, the information is gathered from questionnaires completed by nuclear operators. The key points regarding the sources of uncertainty are as follows:

1. The primary factor contributing to uncertainties lies in the calculation of the total volume flow within the stack.

2. Uncertainties related to sampling are estimated at approximately 10% for aerosol sample collection, 7% for tritium measurement, and 0.4% for noble gas gamma spectrometry.

3. The measuring instrument's contribution to uncertainty is assessed to range from negligible to 10% of the final result.

4. Uncertainties associated with radiochemical techniques vary, ranging from low to 5% for C-14 and H-3 separation from the molecular sieve.

5. Sampling itself does not introduce any additional uncertainty.

6. Instrument calibration uncertainties span from 4% to 15%.

7. The operator's skill in performing sampling and measurements is considered to have a negligible contribution, to 5%.

No specific comments were provided regarding the significance or relevance of this list of uncertainties.

2. France

2.1. Regulatory basis for controls on radioactive discharges

The primary regulatory instruments currently in force are Law 2006-686 of 13 June 2006 and Decree 2007-1557 of 2 November 2007 concerning "Transparency and Security in the Nuclear Field", and among other things, set up the Nuclear Safety Authority (Autorité de Sûreté Nucléaire, ASN) and determines that the ASN defines (in compliance with the general rules), the conditions relative to the design, construction and operation of an installation, which the ASN feels necessary to protect the security, public health, nature, and the environment. In this respect, it specifies, when required, the conditions for water sampling from the installation and radioactive substances from the installation.

The categories of nuclear installations are defined by Law 2006-686 of 13 June 2006. The major installations, such as power stations, are designated as basic nuclear installations (Installation Nucléaire de Base, INB). As of the end of May 2022, there were 124 facilities with "INB" status (see Decision CODEP-CLG-2022-026838 of the President of the Nuclear Safety Authority of June 1, 2022, establishing the list of basic nuclear installations as of May 31, 2022).

Monitoring discharges from a basic nuclear installation (INB) is the responsibility of the installation's operator, according to the Order of 7th February 2012 setting the general rules relative to basic nuclear installations. Two levels of authorization governing the monitoring of radioactive discharges:

- In addition to the applicable national regulations, the requirements governing facility discharges are set by ASN decisions for each INB, which are then ratified by the Ministry of Ecological and Solidarity Transition.
- Procedures and conditions for the intake and consumption of water, and discharges into the environment of liquid and gaseous effluents are specified by the decision of the ASN.

The ASN carries out dedicated inspections to ensure that operators are properly complying with the applicable regulatory provisions concerning the management of discharges. Some of the inspections (10 to 20 inspections per year on the whole national territory) include sampling operations for crosscheck analyses. These inspections are generally unannounced and carried out with the support of specialised independent laboratories commissioned by the ASN. Samples of effluents and samples in the environment are taken for radiological and chemical analyses.

For facilities classed as 'minor' by regulations (i.e. non "INB" in terms of the amounts and types of radioactive materials used), like hospitals, radioactive discharge authorisations are granted as part of the conventional discharge

authorisation by the "Préfet du Département" (In France the "Préfet" is the legal representative of the French State in the Département- regional structure of the French territory), and as necessary, a public inquiry and similar consultations.
In the frame of this study, two nuclear facilities were visited: the reprocessing plant La Hague and EPR NPP in Flamanville (noted Flamanville 3).
The legislative documents giving the framework for radioactive discharge in those facilities are:

The general regulations:

- Environmental Code (R. 593-38)
- Order of 7 February 2012 setting the general rules relating to basic nuclear installations
- Decision No. 2013-DC-0360 of the Nuclear Safety Authority of July 16, 2013, relating to the control of nuisances and the impact on health and the environment of basic nuclear installations (Consolidated version as of December 22, 2016)

Specific to La Hague:

- Decision No. 2015-DC-0535 of the Nuclear Safety Authority of December 22, 2015, lays down the requirements related to the methods of withdrawal, consumption of water and discharge into the environment of liquid and gaseous effluents from basic nuclear installations number: 33 (UP2-400), 38 (STE2 and AT1), 47 (ELAN IIB), 80 (HAO), 116 (UP3-A), 117 (UP2-800) and 118 (processing station STE3 effluents) – Consolidated version of 16 June 2022
- Decision No. 2015-DC-0536 of the Nuclear Safety Authority of 22 December 2015 setting the limit values for discharge into the environment of liquid and gaseous effluents from basic nuclear installations Nos. 33 (UP2-400), 38 (STE2 and AT1), 47 (ELAN II B), 80 (HAO), 116 (UP3-A), 117 (UP2-800) and 118 (STE3 effluent treatment station) – Consolidated version of 16 June 2022.

Specific to EPR Flamanville:

- Decision 2017-DC-0588 of the Nuclear Safety Authority of 6 April 2017 setting the procedures for water withdrawal and consumption, discharge of effluents and monitoring of the environment of pressurized water nuclear power reactors,
- Decision 2018-DC-0639 of the Nuclear Safety Authority of July 19, 2018, setting to Electricité de France – Société Anonyme (EDF-SA) the discharge limits of gaseous effluents the environment for the operation of reactors "Flamanville 1" (INB no. 108), "Flamanville 2" (INB no. 109) and "Flamanville 3" (INB no. 167),
- Decision No. 2018-DC-0640 of the Nuclear Safety Authority of July 19, 2018, setting the requirements relating to the methods of water withdrawal and consumption, discharge of effluents and environmental monitoring basic nuclear installations no. 108, no. 109 and no. 167 operated by Electricité de

France (EDF) in the municipality of Flamanville.

2.2. Discharge limits in effect

The discharge limits in effect are expressed in:
- The rates of individual or group of radionuclides released, TBq/y;
- And in terms of concentration, Bq/m^3 and Bq/l for liquid discharges;
- For gaseous and liquid discharges, there are limits fixed by regulation for "instantaneous activity flowrates" in Bq/s.

La Hague

For the Orano La Hague site, the annual limits of the activity of radioactive discharge released into the atmosphere in gaseous or aerosol form are provided in Table 2.

Table 2: The annual limits of the activity of radioactive effluent released into the atmosphere in gaseous or aerosols

Radionuclide	Limits TBq/year
Tritium	150
Carbon-14	28
Noble gases	470,000
Iodines (129,131)	0,018
Other radionuclides (beta and gamma)	0,001
Other radionuclides (alpha)	0,00001

The limits imposed to La Hague facility as activity concentrations measured after dispersion in the air at ground level via the sampling stations. The sampling conditions are provided in Table 3.

Table 3: The limits as activity concentrations measured after dispersion in the air at ground level at the sampling stations and under the sampling conditions

Radionuclide	Activity concentration	Frequency
Tritium	8 Bq/m^3	weekly
Carbon-14	1 Bq/m^3	monthly
Noble gases	1 850 Bq/m^3	monthly
Iodines (129,131)	3,7 10^{-2} Bq/m^3	weekly
Other radionuclides	10^{-3} Bq/m^3 alpha overall	daily
Other radionuclides	10^{-3} Bq/m^3 beta overall	daily

The monthly activity of discharges in gaseous should not exceed one-sixth of the corresponding annual limits. The annual limits for the liquid radioactive discharges are provided in Table 4.

Table 4: The annual limits for the liquid radioactive effluents

Radionuclide	Limits relating to discharges from routine operations (TBq/year)	Additional limits specific to discharges from authorized operations for recovery and conditioning of old effluents, final shutdown and dismantling (TBq/year)
Tritium	18 500	
Iodines	2.6	
Carbon 14	42 for liquid and gaseous discharges (so actual limit is rather 42 - 28 = 14)	
Strontium 90	0.6	9.8
Caesium 137	1.6	4
Caesium 134	0.35	
Ruthenium 106	7.5	
Cobalt 60	0.5	0.5
Other emitters Beta and gamma	12	25
Emitters Alpha	0.07	0.07

The liquid effluent discharged into the Moulinets dam and into the Moulinets, Sainte-Hélène, and Combes streams respectively should have the activity lower than:

- 200 Bq/l in tritium,
- 0.2 Bq /l in alpha,
- 1 Bq/l in beta and
- 1 Bq/lin gamma.

Also, the tritium activity, calculated as a weekly average, should not exceed 100 Bq/l.

Flamanville 3

The discharge limits of gaseous effluents for the operation of reactors: “Flamanville 1” (INB no. 108), “Flamanville 2” (INB no. 109) and “Flamanville 3” (INB no. 167) are provided in Table 5.

Table 5: Annual gaseous discharge limits

Radionuclide	Annual activity(in GBq)
Carbon-14	2 300
Tritium	11 000
Noble gases	40 000
Iodine	1
Other radionuclides	0.15

The stack activity flowrate of each INB shall comply with the limits in Table 6.

Table 6: Limit of the gaseous activity flow rate

Radionuclide	Activity flow per stack (in Bq/s)-FLA1/2	Activity flow per stack (in Bq/s)-FLA3
Tritium	$1,2x10^6$ (1)	$9x10^5$ (1)
Noble gases	$1x10^7$ (2)	$1x10^7$ (2)
Iodine	$1,1x10^2$ (3)	$1,1x10^2$ (3)
Other radionuclides	$1,1x10^2$ (4)	$1,0x10^2$ (4)

These activity rates must be respected:
- for noble gas discharges, as an average over 24 hours;
- for the other parameters, as an average over each of the 4 monitoring periods defined by the regulation.

1) This activity flow may be exceeded without however the activity flow for the entire Flamanville site exceeding $3.3.10^6$ Bq/s.
(2) This activity flow may be exceeded without however the activity flow for the entire Flamanville site exceeding $3.0.10^7$ Bq/s.
(3) This activity flow may be exceeded without however the activity flow for the entire Flamanville site exceeding $3.3.10^2$ Bq/s.
(4) This activity flow may be exceeded without however the activity flow for the entire Flamanville site exceeding $3.2.10^2$ Bq/s.

The discharge limits of liquid effluents into the environment for the operation of reactors:

> "Flamanville 1" (INB no. 108), "Flamanville 2" (INB no. 109) and "Flamanville 3" (INB no. 167) are provided in Table 7.

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Table 7: Annual liquid discharge limits.

Radionuclide	Annual limits (in GBq)
Tritium	145 000 + 10 000 x N (1)(2)
Iodine	0.12
Carbon 14	280
Other fission or activation products (beta or gamma emitters)	13

(1) N: number of reactors (INB 108 and INB 109) with high burnup fuel management

(2) The limits applicable for the management of fuel with a high burnup rate only come into force following a decision by the Nuclear Safety Authority. In cases where different fuel management modes are implemented on the same reactor during a calendar year, the annual limit will be calculated pro rata temporis of the respective operating times of the two fuel management modes. Reactor shutdown time counts for the previous cycle.

In addition, the activity flow rate in the discharge basin at the point of discharge into the sea, for a flow D (in l/s) in the cooling water pipe should not exceed, as an average value over 24 hours, the limits in Table 8.

Table 8: Limit of the liquid activity flow rate

Radionuclide	Activity rate (Bq/s)
Tritium	800 x D
Iodine	1 x D
Other fission or activation products (beta or gamma emitters)	7 X D

2.3. Reporting obligations on discharge monitoring

To demonstrate compliance with their discharge authorisations, operators are required to undertake sampling, measurements, and/or assessments of the discharges and their effects on the environment. These requirements depend on the operations at each site and its environment and are detailed in the site specific decision document and procedures. Those regulatory documents also detail the operator’s required schedule for the reporting of discharge and environmental measurements to the ASN. This monitoring is carried out on liquid and gaseous effluents (monitoring the radioactivity of discharges, characterising certain effluents before discharge, etc.) and on the environment in the vicinity of the installation (checks during discharge, sampling of air, water, milk, grass, etc.). The findings of this monitoring are entered in registers and sent to the ASN each month.

In addition, the INB operators regularly send a certain number of discharge samples to an independent laboratory for comparative analysis. The results of these crosschecks are sent to the ASN. This programme of crosschecks makes it possible to ensure that the measurements carried out by the operators' laboratories are correct.

In addition, the operator is obliged to issue the annual information report required by article L. 125-15 of the Environmental Code, which states that every operator of an INB (Installation Nucléaire de Base) shall prepare an annual report which shall contain information concerning:

- The measures taken to prevent or limit the risks or inconveniences that the installation may present for the interests mentioned in article L 593-1;
- The incidents and accidents subject to the obligation of declaration in application of article L 591-5, which have occurred within the perimeter of the installation, as well as the measures taken to limit their development and the consequences for human health and the environment;
- The nature and results of measurements of radioactive and non-radioactive releases from the facility into the environment;
- The nature and quantity of radioactive products stored within the perimeter of the facility, as well as the measures taken to limit its volume and its effects on health and the environment, particularly on soil and water.

In accordance with the provisions of article L. 125-16 of the Environmental Code, this report is submitted to the competent employee representative body (CSE), which may make recommendations. These recommendations are attached to the document for publication and transmission.
This report is made public and sent to the Local Information Commission (CLI) and the High Committee for Transparency and Information on Nuclear Safety (HCTISN).

2.4. Compulsory technical requirements

For each INB in France, the compulsory technical requirements are specified in the facility-specific decisions such as:

- The requirements governing facility discharges that are set by ASN decisions and ratified by the Ministry of Ecological and Energy Transition;
- Procedures and conditions for the intake and consumption of water and discharge into the environment of liquid and gaseous effluents specified by the decision of the ASN.

Decision thresholds for environmental monitoring are defined in the ASN resolution 2013-DC-0360 (consolidated version form December 2016) within Art 3,3,4-I.

For discharge monitoring, the regulation imposes decision thresholds for global alpha activity:

- 0,001 Bq/m^3 for permanent gaseous discharges and 0,025 Bq/m^3 for each individual discharge operation;
- 1 Bq/l for liquid discharges for each individual discharge operation and 0,37 Bq/l for monthly aliquot.

In France, discharge monitoring and environmental monitoring laboratories should comply with NF-ISO-CEI 17025, but they do not necessarily have to be accredited. However, environmental monitoring laboratories must obtain ASN approval, amongst other through their success in the interlaboratory exercises organised by IRSN.

2.5. Main strengths and weaknesses of monitoring radioactive discharges

The French Safety Authority, at the time of the study, considered that there was no need for better monitoring methods and techniques. The development of the best monitoring methods/techniques is assured with the support of the technical expert, IRSN, with additional participation in standards bodies (BNEN, ISO) and some technical working groups (CETAMA - GT14, 18 and 31 dealing respectively with radionuclides monitoring in effluents, water, and environment).

Uncertainties

The uncertainties originate mainly from the assessment of the flow in the stack for gaseous discharges, and the estimation of the total volume in the tanks for liquid discharges.

EDF, Flamanville:

For Gaseous Discharges:

The total volume flow represents the major uncertainty factor, estimated approximately at 10% on the KRT channels (EPR Flamanville), 7% for the tritium measurement, and 0.4% for the inert gases gamma spectrometry.

For Liquid Discharges:

The means of accounting for volumes of liquids in tanks represent the major uncertainty factor.

In addition, EDF reported that tests carried out in Cattenom at the end of 2005-beginning of 2006, following the "Tritium Park Alert", show that direct sampling from the stack is a good solution, while sampling from a bypass risks being non-representative (reference document "Système élémentaire KRT Pièce P2 - Fonctionnement du système").

ORANO, La Hague:

During our survey, the Orano La Hague facility has not reported the uncertainties related to the assessment of the flow in the stack for gaseous discharges.

Periodic evaluation of discharge limits

Periodic evaluation of discharge limits is required by regulation approximately every 10 years. On this occasion, the operator must:
- justify its practises compared to the best available techniques;
- check the consistency of the discharge limits based on the feedback of operation and propose revised limits if necessary.

Consequently, ASN may revise the discharge limits as necessary.

Best practices

The EPR reactor in Flamanville is equipped with on-line/continuous stack spectrometry for noble gases, while the other units of Flamanville rely on continuous sampling method, which allows on-line monitoring of sudden releases.

2.6. Compliance with Recommendation 2004/2/Euratom

In the frame of the study, two facilities were visited in France, Orano La Hague and EPR Flamanville. As the EPR reactor is still under construction, compliance with Recommendation 2004/2/Euratom and gap analysis were performed only on the Orano La Hague reprocessing plant example.

ASN reported satisfying relevance with the French regulations. It should be noted, however, that:

- The French regulations do not impose reporting of the highest value of the detection limit[3] that has been obtained among all the measurements for the period considered. The detection limits are, however, registered and can be provided by the facility operator.
- The French regulations do not impose a distinction between organic and inorganic forms of C-14 in the context of monitoring gaseous releases. C-14 releases from French facilities are mainly in inorganic form. Gaseous iodine releases are monitored using activated carbon trap cartridges.
- For radionuclides in the reference spectrum, when a measurement result is below the decision threshold, article 3.2.8 of ASN decision no. 2013-DC-0360 requires nuclear operators to declare a discharge equal to the decision threshold to be sure not to underestimate the declared discharge. On the EC

[3] detection limit: the smallest true value of the measurand that is detectable, with a given probability of error, by the measuring method.

RADD, we do not find the information whether the reported values come from measurement or decision threshold.

- The French regulations specify the requirements applicable to sample collection methods in the context of monitoring releases (in particular, article 3.2.20 of ASN decision 2013-DC-0360). On EC RADD, we do not find the information on the sampling method for the effluent streams.
- The detection limits for the measurements are not always smaller than the ones in Recommendation 2004/2/Euratom (in the case of Kr-85 for gaseous discharges and Co-60/Sr-90/I-129 for liquid discharges).

3. Belgium

3.1. Regulatory basis for controls on radioactive discharges

The Belgium Federal Agency for Nuclear Control (FANC) is the regulatory body in charge of monitoring, controlling, and checking all practices involving ionising radiation. FANC is responsible for, among other things, licensing nuclear and radiological installations, monitoring compliance with the rules and standards, and monitoring radioactivity in the environment. The FANC is under the supervision of the Minister of the Interior of Belgium.

Operationally, the FANC has four departments:

- Facilities and Waste
- Health and Environment
- Security and Transport
- Support

The first two departments (Facilities & Waste and Health & Environment) are particularly concerned with radioactive discharges, with a mission of surveillance of the environment.

In Belgium, the various establishments that use radioactive substances or equipment capable of emitting ionising radiation have been divided into four classes of establishments according to the quantities of radioactive substances held, the power of the device or the activity of the sources held:

- Class I, the large facilities, such as nuclear power reactors, fuel cycle plants, large nuclear research establishments and waste disposal facilities;
- Class II, such as smaller research establishments, hospitals, and universities;
- Classes III and IV, which are of less significance, involve small apparatus and radioactive sources.

The classification rules are laid down by Royal Decree (Article 3.1 of the Royal Decree of 20 July 2001 on the general regulations for the protection of the population, workers and the environment against the danger of ionising radiation). The classifications are based on the importance of the potential risk of the operation.

Because the IRE, a nuclear installation that is part of the study, disposes of fissile material, FANC registers it as a class I establishment.

Bel V is a subsidiary and has acted as a technical support organisation (TSO) for FANC since April 14, 2008. It took over the regulatory controls in class I/IIA nuclear installations formerly carried out by the Authorized Inspection Organization. In Belgium, FANC relies on the technical expertise of Bel V for carrying out inspections in nuclear power plants and other nuclear installations (hospitals, universities and radionuclide production facilities). Bel V's experts participate in the safety assessments of nuclear projects, meetings and working groups that are organized in the framework of international organizations (EC, OECD, IAEA). Bel V exchanges information and experience feedback with Belgian and foreign institutions and contributes to the emergency plans for nuclear accidents.

FANC, alongside its TSO Bel V, has a campaign of inspections on the radiological impact of the facility on the environment. In the frame of these inspections, the monitoring systems of radioactive discharge are inspected at least every three years.

The legislative documents giving the framework for radioactive discharge are:

- Royal Decree of 20 July 2001 laying down general regulations for the protection of the population, workers and the environment against the danger of ionizing radiation;
- Law of 15 April 1994 relating to the protection of the population and the environment against the dangers of ionizing radiation, and relating to the Federal Agency for Nuclear Control;
- Technical regulations of the Federal Agency for Nuclear Control of 07/05/2019 setting the criteria for reporting and analysis to the Federal Agency for Nuclear Control of significant events related to the radiation protection and/or the safety of workers, the public, and the environment in establishments class I;
- Periodic reporting to FANC and Bel V of liquid and gaseous radioactive discharge - 010-106 rev 1.

3.2. Discharge limits in effect

Regulation for gaseous and liquid discharge can be found in the Royal Decree of 20th July 2001. The limits for the monitored radionuclides are found in Appendix III of Table H1 (for liquid discharge) and Table H2 (for gaseous discharge) of the Royal Decree.
The limits are expressed in terms of concentration for every radionuclide in Bq/m^3 when gaseous and in Bq/l when liquid.
Gaseous radioactive discharges in the atmosphere are forbidden if the nuclide concentration exceeds a certain concentration corresponding to a dose of 1mSv/year for a person continuously exposed to the discharge. Liquid radioactive discharges in water or sewers are forbidden if the nuclide concentration exceeds one-thousandth of the annual concentration limit.
But the IRE has specific limits for a certain number of radionuclides that are higher than the limits given in the Royal Decree. These limits are expressed in rates of individual radionuclides released (in Bq/year or Bq/week).

3.3. Reporting obligations on discharge monitoring

The operator must establish a monthly and an annual report and send them to FANC and Bel V as detailed in the *Periodic declaration to the AFCN and Bel V concerning the discharge of liquid and gaseous radioactive effluents*

(04/21/2020).

The monthly report must include, among other requirements:

- Volumes discharged for each radionuclide or group of radionuclides (in m^3)
- Detection limit for key radionuclides
- The discharged activity (in MBq)
- Cumulated values since the beginning of the year and cumulated fractions of the limits

The annual report must include, among other requirements:

- A summary of the main discharges over the year
- The discharge limits to which the establishment is subject:
    - Annual limits (or 52 rolling weeks, if applicable)
    - Limits for shorter periods
    - Operating constraints, if any
- A brief description of the methods and techniques for determining the activity released
- A detailed justification of the development of the annual discharge trends
- Any planned improvements to reduce the impact of discharges (ALARA principle)
- A calculation of the annual dose to the population based on the reported discharges.

3.4. Main strengths and weaknesses of monitoring radioactive discharges

Extension of Recommendation 2004/2/Euratom

FANC and Bel V issued a document entitled: "Periodic declaration to the AFCN and Bel V concerning the discharge of liquid and gaseous radioactive effluents", giving the rules on how to declare discharges to the regulator, explaining how to evaluate the discharge based on Recommendation 2004/2/Euratom and Directive BSS. Even though Recommendation 2004/2/Euratom concerns nuclear power plants and reprocessing plants, FANC and Bel V decided to extend the implementation of certain aspects of this Recommendation to any other facilities with a discharge permit, such as the processing facility IRE. Nevertheless, the specificity of each establishment is considered by FANC. The regulator will receive harmonised reports from all Belgium facilities.

Discharge limits

There are several ways in which discharge limits are expressed in regulations by Member States. Belgium combines two ways which makes it robust:

- Primarily, limits are expressed in terms of concentration (e.g., Bq/m^3 or Bq/l);
- Secondly, and not systematically, limits are also expressed as rates of

individual or grouped radionuclides released (e.g., Bq/year).

On-line monitoring of noble gases

The on-line monitoring of noble gases is a best practice at IRE. Through the activated carbon filters, the xenon is slowed down, and the HPGe spectrometers continuously measure the xenon activity allowing the monitors to see sudden changes.

3.5. Compliance with Recommendation 2004/2/Euratom

Recommendation 2004/2/Euratom recommends monitoring a list of radionuclides. These radionuclides are reported in the European Commission RAdioactive Discharges Database (RADD).

In the database, NPPs in Belgium indicate the gaseous releases for:

- Tritium
- Total alpha
- Total Beta/gamma-emitting particulates (excluding iodine)
- Total noble gases
- Total iodine (specific to isotope)

Table 9 presents the result of a gap analysis for the key radionuclides that should be monitored for liquid discharge according to Recommendation 2004/2/Euratom and if they are reported in the EC RADD Database.

Table 9: Radionuclides for liquid discharge reported in the EC RADD database.

	Doel	Tihange
S-35	N/A, not a gas-cooled reactor	N/A, not a gas-cooled reactor
Co-60	Yes	Yes
Sr-90	Yes	Yes
Cs-137	Yes	Yes
Pu-239+Pu-240	No	No
Am-241	No	No
H-3	Yes	Yes
Total alpha	Yes	Yes

Doel and Tihange NPPs do not report in the EC RADD database the releases of Pu-239 and Pu-240 and Am-241.

4. The Netherlands

4.1. Regulatory basis for controls on radioactive discharges

The Authority for Nuclear Safety and Radiation Protection (ANVS) ensures that the highest standards of nuclear safety and radiation protection are met in the Netherlands. The ANVS has the responsibility of issuing licences, ensuring that licence-holders abide by those requirements and, if the need arises, taking enforcement actions.

The ANVS was formed in 2015 and became an independent administrative authority in 2017. The ANVS is within the Minister of Infrastructure and Waste Management.

The ANVS's Technical Support Organization (TSO) is a conglomerate of three parties: Bel V, IRSN, and Bureau Veritas. The TSO can perform a wide variety of tasks, including reviewing licensees' reports. Additionally, the National Institute for Public Health and the Environment (RIVM) provides technical and scientific support. RIVM performs monitoring contamination levels within and outside the nuclear site and analysing filters and samples from discharges and counter-expertise measurements. Every year, RIVM performs eight counter-expertise projects that aim at verifying and supporting the reliability of the analyses carried out by NRG.

Moreover, the discharge monitoring system is inspected approximately every five years. Discharge monitoring is also a major component of the periodic safety evaluation (every ten years).

The legislative documents giving the framework for radioactive discharge are:

- Basic Safety Standards Radiation Protection Decree
- ANVS-order Basic Safety Standard Radiation Protection
- Nuclear Installations, Fissionable Materials and Ores Decree
- Nuclear Energy Act Licence

The ANVS has issued two licences for Petten based on the "Kernenergiewet" -the nuclear energy act which covers all matters to do with radioactivity, including the authorisation and licensing of activities involving radioactive substances.

4.2. Discharge limits in effect

Petten's licence does not fix annual limits in terms of activity in Bq. The limits are quantified in radiotoxicity equivalent. The quantity "radiotoxicity equivalent" (Re) is the activity which, at intake, results in a committed effective dose of 1 sievert. The corresponding unit is Bq. The radiotoxicity equivalent is the inverse of the dose conversion coefficient e(50):

$$1\ Re\ [Bq] = \frac{1\ [Sv]}{e(50)\ [{}^{Sv}/_{Bq}]}$$

EQUATION 1 – DEFINITION OF THE RADIOTOXICITY EQUIVALENT RE

The value of the radiotoxicity equivalent strongly depends on the nuclide, and the chemical properties of the radioactive substance. If the chemical composition of the radionuclide is unknown, the most conservative value of Re is used.

The values of the dose coefficient e(50) are taken from the ICRP-11.

The radiotoxicity equivalent is defined as ingested (Re_{ing}) for liquid effluents and inhaled (Re_{inh}) for gaseous effluents.

This way of defining limits is a risk-based concept and is radionuclide independent.

Noble gases do not have an e(50). Validated by ANVS, NRG uses an empirical expression which is based on the Derived Air Concentration (DAC) of ICRP-30 (1).

$$1\ Re = DAC\ ({}^{1}/_{200})[Bq.m^{-3}] * 5.10^{6}[m^{3}]$$

EQUATION 2 – EMPIRICAL EXPRESSION OF THE RADIOTOXICITY EQUIVALENT FOR NOBLE GASES

4.3. Reporting obligations on discharge monitoring

Reporting happens once every three months to the safety authority. An annual report on radiation protection, including information on discharges, is produced by the operator.

4.4. Compulsory technical requirements

There are no specific requirements other than the annual limit expressed in radiotoxicity equivalent (Re). Table 10 gives the annual limits in Re_{inh} for gaseous discharge of each Petten facility.

Table 10: Annual limits (in R_{einh}) of each facility on Petten

Facility	Annual limit (Re_{inh}/year)
High Flux Reactor (HFR)	100
Decontamination and Waste Treatment (DWT)	10
Hot Cells Laboratories (HCL)	60
Waste Storage Facility (WSF)	20
Radionuclide Laboratories	5

4.5. Main strengths and weaknesses of monitoring radioactive discharges

Discharge limits

The way of expressing discharge limits is a formula for limitation which allows for the radiological significance of different radionuclides. According to the *Overview of National Radioactive Discharge and Environmental Monitoring Requirements in the European Union in Furtherance of Article 35 of the Euratom Treaty* report, this method has the disadvantage of being less transparent, and is likely to need time before any potential breach of authorisation can be discovered. Furthermore, the same report states that this method could imply a more generous release rate for some radionuclides than may be justifiable. Thus, weighing the advantages and disadvantages, the best practice seems to be setting discharge rates for individual radionuclide (e.g., in TBq/y) limits.

The equipment used for monitoring

The team suggests modernizing some of the equipment used for monitoring, namely the Geiger-Müller detectors for the on-line monitoring of the HFR.

Needs for development

Although Petten Nuclear site is not concerned by Recommendation 2004/2/Euratom (which requires to report C-14 releases), we suggest, that that Petten nuclear site includes monitoring of this radionuclide in liquid discharges.

4.6. Compliance with Recommendation 2004/2/Euratom

Recommendation 2004/2/Euratom does not concern research reactors and radioisotope-producing facilities. The Netherlands' only commercial nuclear reactor, the Borssele nuclear power plant, regularly reports radionuclide-specific data on the EC RADD. The distinction between organic and inorganic forms of C-14 is well-reported.

5. Sweden

5.1. Regulatory basis for controls on radioactive discharges

The Swedish Radiation Safety Authority (SSM) is the responsible national authority for nuclear safety, radiation protection, nuclear security, and nuclear non-proliferation. It operates under the responsibility of the Ministry of Environment. The SSM is a legally binding regulatory body that oversees licensing, carries out inspections, issues regulations and enforces the issued regulations.

SSM took over the responsibilities and tasks from the Swedish Radiation Protection Authority (SSI) and the Swedish Nuclear Power Inspectorate (SKI) in 2008.

SSM has no technical support organization (TSO) but has an R&D program with a focus on research and scientific expertise. There are no ongoing projects regarding discharge monitoring at the time this report is written.

The framework of Sweden's nuclear and radiation protection regime can be found in five acts:

- Environmental Code (SFS 1998:808), which addresses environmental aspects of nuclear activities and lists "nuclear activities" among several other "environmentally hazardous activities".
- Nuclear Activities Act (SFS 1984:3), which mainly concerns security and control issues and the overall safety of nuclear operations.
- Radiation Protection Act (SFS 1988:220), which aims to protect people, animals and the environment from the harmful effects of radiation.
- Act on Financing of Management of Residual Products from Nuclear Activities (2006:647), which contains provisions for the future costs of spent fuel and nuclear waste disposal, decommissioning of reactors and other nuclear installations and research in the field of nuclear waste.
- Nuclear Liability Act (SFS 1968:45) which implements Sweden's obligations as a party to the 1960 Paris Convention on Third Party Liability in the Field of Nuclear Energy and the 1963 Brussels Convention Supplementary to the Paris Convention.

The regulatory texts provided by SSM for the control of discharges from nuclear power plants are:

- Swedish Radiation Safety Authority Regulatory Code SSMFS2021:4, 5 and 6 issued on 1 March 2022,
- Swedish Radiation Safety Authority Regulation Code SSMFS 2018:1 (2) issued in 2018,
- Decision of the Radiation Safety Authority amending Decision SSM 2010/1155 issued on 4 august 2010,
- Swedish Radiation Safety Authority Regulatory Code SSMFS 2008:23 issued on 19 December 2008.

SSM's regulatory framework is in a transition period. SSMFS2021:4, 5 and 6 were issued in 2021 but there are some requirements that will only start being enforced in 2024. During this transition period parts of previous texts (SSMFS 2008:23 and SSM 2010/1155) are still valid.

5.2. Discharge limits in effect

Swedish regulation does not impose discharge limits; there are no annual nuclide-specific release limits. The discharge limits are set as a dose to a representative person near the plant as a result of the combined effluents from all discharge points. According to SSMFS 2021:6, the equivalent dose to this representative person must not exceed 0,1 mSv/year.

NPPs, such as Forsmark, measure the discharges (in Bq) and calculate an annual release rate (in Bq/year). Then, by multiplying this annual release rate with a release-to-dose factor (in Sv/year per Bq/year), the dose to the member of the public is found. These dose factors are nuclide specific and have been modelled within a very comprehensive project called PREDO (PREdication of Doses from normal releases of radionuclides to the environment). The PREDO study was issued in 2015 and replaced release-to-dose factors established by the industrial group Studsvik. The SSM has reviewed and accepted the PREDO methodology to be used for the estimation of the radiation doses to the public. Since the dose to a human can only be estimated, the PREDO study develops four main models:

- the air dispersion and deposition modelling
- the terrestrial transport modelling
- the aquatic transport modelling for discharges to the sea
- the dose modelling

The factors are not only specific to every plant in Sweden but also specific to each discharge point of a plant. The representative persons are of different age groups and family types (average, vegetarian, farmer, hunter etc.). Therefore, for each release point and each radionuclide, several dose factors will be obtained, corresponding to the different representative persons initially considered.

The representative people taken into consideration are three age groups (infants, children, and adults) belonging to the following family types:

- Average family
- Farmer (general) family
- Farmer (dairy producer) family
- Fisherman family
- Hunter family
- Vegetarian family

An analysis of these dose factors was performed to select the final factors that are used for the calculation of doses for the Forsmark. The doses to individuals of the average family and the most exposed family are reported to the SSM.

5.3. Reporting obligations on discharge monitoring

Approved discharge data is exported from the database to a calculation tool that calculates monthly and annual discharges and applies dose factors to provide an estimated effective dose to the representative persons in the vicinity of the plant. The tables that are generated by the calculation tool are used for further reporting, monthly and annually.

NPPs must prepare a monthly report to provide input to the follow-up of discharges that are made throughout the year. For example, the Forsmark indicator system includes several indicators related to discharges. In addition to the monthly discharges, it includes basic information, accumulated discharges and figures that can be used by the recipients of the report.

An annual discharge report is prepared and is to be made available to the regulator within three months after the end of the year. There are topics that must be included in the report according to the regulations. Other sections are included to provide useful information, such as long-term trends and benchmarking. In addition to the annual report, the regulator has also requested that the Swedish plants supply a complete history of previously reported releases. At Forsmark, this is done by an annual update of a historical database that was compiled for this purpose.

The table of contents of the most recent annual report is as follows:

1. Summary
2. Background
    - 2.1. Purpose
    - 2.2. Controlled release paths
    - 2.3. Discharge restrictions
3. Methods
    - 3.1. Sampling
    - 3.2. Analysis
    - 3.3. Detection limits
    - 3.4. Uncertainties
    - 3.5. Dose conversion
4. Discharges
    - 4.1. Overview of production
    - 4.2. Discharge compilation
    - 4.3. Long-term trends
    - 4.4. Diffuse leakage

   4.5. Special discharges
5. Comparisons
   5.1. SSM dose restrictions
   5.2. Reference and goal values
   5.3. International benchmarking
6. Evolution of the annual report
7. References
8. Appendices

In addition to the annual report, the regulator has also requested that all Swedish plants supply a complete history of previously reported releases. Forsmark updates annually a database with historical effluent reporting.

5.4. Main strengths and weaknesses on monitoring radioactive discharges

Discharge limits are expressed as dose to a representative person of the public

Sweden expresses the limit in terms of dose to the critical group or representative person, and not in as rates of individual or grouped radionuclides (typically in terabecquerels per year). Whilst this method clearly reflects the objective to limit dose, it relies on models involving dispersion, environmental and human uptake, habits data, and other factors which may be uncertain to the operator because there is limited control.

Even though the limits are expressed in terms of a dose to the critical group, the Swedish operator must report all measured radionuclides to SSM via reports. Moreover, the operator defines, for each plant, reference values corresponding to an expected release based on previous years' data. Every five years, the operator establishes goal values (equal to or smaller than the reference values), which are the annual target to reach in terms of releases. Reference and goal values are nuclide specific. These goal values are communicated to the regulator. The annual discharges are compared to the reference and goal values, and an evaluation is to be submitted to SSM. Each month NPP chemistry departments in charge of monitoring releases issue an internal report with comparisons of goal value against the reference value. Any deviation from reference values must be explained.

Annual reporting to SSM

The reporting to the SSM by the operator has progressed over the years. Developments of the report in recent years include combined uncertainties (since 2021), analysis of diffuse leakages (since 2020), BWR discharge benchmarking (since 2014), detection limits included in effluent calculations (since 2011), continuous refinement in nuclide selection and representativity.

Uncertainties

The uncertainties originate mainly from the assessment of the flow in the stack. For Forsmark, the flow meter is checked and calibrated annually according to the maintenance program. During operation, the flow appears to be quite stable (not fluctuating). Forsmark estimates combined uncertainties for the release of activity, which requires (among many other things) some assumption about the uncertainty of the main stack flow. That assumption is currently that the stack flow measurement can vary +/- 5% with a quadratic distribution which corresponds to a standard uncertainty for the flow of 1.73%. This does not include any systematic error.

5.5. Compliance with Recommendation 2004/2/Euratom

Table 11 presents the result of a gap analysis for the key radionuclides that should be monitored for gaseous discharge according to Recommendation 2004/2/Euratom and if they are reported in the EC RADD.

Table 11: Compliance with Recommendation 2004/2/Euratom for key radionuclides in gaseous discharge of Forsmark NPP

Key Radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database?	Highest value of detection limit achieved at facility (Bq/m3)	Detection limit in Recommendation (Bq/m3)
Kr-85 (1)	Yes	See comment below	1.00E+04
Xe-133	Yes	8.70E+01	1.00E+04
Co-60	Yes	2.00E-04	1.00E-02
Sr-90	Not reported on RADD but is monitored nevertheless	1.06E-04	2.00E-02
S-35	N/A because Forsmark is not a gas-cooled reactor	N/A	N/A
Cs-137	Yes	1.95E-04	3.00E-02
Pu-239+Pu-240	Yes (but not in 2019)	2.72E-08	5.00E-03
Am-241	Yes (but not in 2019 nor 2021)	1.92E-09	5.00E-03
I-131	Yes	2.00E-03	2.00E-02
H-3	Yes (not in 2021)	6.75E-01	1.00E+03
C-14	Yes (not in 2021)	8.06E-01	1.00E+01

(1) Kr-85: Kr-85 is not directly measured because if Kr-85 was measured in the online noble gas monitoring, the positron annihilation peak would interfere with the Kr-85 peak. This problem could be solved by making a sample withdrawal and decay of the positron source, but there would be a risk of missing sudden releases.

The method used is a calculation, based on how much fissile material has contaminated the fuel bundles and on the number of fuel failures. This explains why no detection limit is given for Kr-85.

Table 12 presents the result of the gap analysis for radionuclides found in liquid discharge for Forsmark NPP.

Table 12: Compliance with Recommendation 2004/2/Euratom for key radionuclides in liquid discharge

Key Radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database?	Highest value of detection limit achieved at facility (Bq/m3)	Detection limit in Recommendation (Bq/m3)
S-35	N/A because Forsmark is not a gas-cooled reactor	N/A	N/A
Co-60	Yes	2.58E+02	1.00E+04
Sr-90	Not reported on RADD but is monitored nevertheless	7.85E+01	1.00E+03
Cs-137	Yes	2.06E+02	1.00E+04
Pu-239+Pu-240	Yes (but not 2016, 2017, 2020, 2021)	7.30E-07	6.00E+03
Am-241	Yes (but not in 2017)	1.07E-07	5.00E+01
H-3	Yes	1.80E+04	1.00E+05

The reason why some radionuclides are reported or unreported to the EC RADD is unknown to the team. As for the Sr-90, this radionuclide is indeed monitored but, evidently, is not reported to the EC RADD.

The detection limits for the measurements are very good, as they are generally 100 times smaller than the ones in Recommendation 2004/2/Euratom.

Article 8(d) of Recommendation 2004/2/Euratom states that: "Member States should report the following information [..]: as far as available, the chemical/physical form of tritium, carbon-14 and iodine discharges to the atmosphere."

In the annual Forsmark NPP discharges, reported to the EC RADD, do not include the chemical/physical form of these three radionuclides.

6. Finland

Fortum-operated Loviisa Nuclear Power Plant (NPP) with two PWR units (LO1 & LO2) and TVO operated Olkiluoto NPP with EPR unit (OL3) were under the survey in Finland.

LOVIISA (LO1 & LO2)

Loviisa NPP is composed of two modified (including containment building and ice condenser) VVER-440 pressurised water reactor (PWR) units (LO1 with an electrical capacity of 507 MW and LO2 with a capacity of 507 MW and combined thermal capacity of 3000MW). Annual production is approximately 8.2 TWh which presents 10% of Finland's electricity production (2021). Light water is used for cooling and moderating with the ultimate heat sink being seawater. The maintenance is done annually, and the capacity factor in 2021 was 92.9%. Both reactors have individual reactor buildings but share a turbine building. Commercial operation of the LO1 reactor started on 9 May 1977 and LO2 on 5 January 1982. In 2014, Fortum (operator) contracted Rolls-Royce to support the modernisation of safety-related systems, including a change to digital automation, for both Loviisa units. The nominal electric capacities of the reactors were upgraded by about 10 % to the current level at the end of the project in 2018.

OLKILUOTO (OL3)

The OL3 unit of PWR type is commissioned for commercial operation on a plant site where two boiling water reactor (BWR) units of Asea Atom design, Olkiluoto Unit 1 (OL1) and Olkiluoto Unit 2 (OL2), are already operated by TVO. OL3 is an EPR-type reactor (European Pressurized water Reactor) with a net electrical output of approximately 1,600 MW. The commercial operation of OL3 is expected to start in late 2022. The OL3 is one of the five nuclear power units in Finland, and it produces approximately 16% of the country's electricity needs, where about 44 % of the total electricity needs will be produced by nuclear power.

6.1. Regulatory basis for controls on radioactive discharges

The discharge monitoring programme is based on YVL C.3 guidance, which sets the requirements for a licensee on which radionuclides must be measured in liquid and gaseous releases.

Discharge monitoring and reporting are regulated by the following:

- The Radiation Act (859/2018) contains general provisions for limiting radiation exposure. www.stuklex.fi/en/STUK-Y-4-2018_perust.pdf
- The Government Decree on Ionising Radiation (1034/2018)

- The Radiation and Nuclear Safety Authority Regulation on the Safety of a Nuclear Power Plant (STUK Y/1/2018). www.finlex.fi/data/normit/42574/STUK-Y-1-2018.en.pdf
- Nuclear Energy Act 11.12.1987/990
- Nuclear Energy Decree 12.2.1988/161
- Radiation and Nuclear Safety Authority Regulation on the Safety of a Nuclear Power Plant, STUK Y/1/2018
- Radiation and Nuclear Safety Authority Regulation on the Emergency Arrangements of a Nuclear Power Plant STUK Y/2/2018 (need for measurements is mentioned)
- YVL A.6 Conduct of operations at a nuclear power plant, 15.6.2019. https://www.stuklex.fi/en/ohje/YVLA-6
- YVL C.6 Radiation Monitoring at a Nuclear Facility, 15.3.2019. https://www.stuklex.fi/en/ohje/YVLC-6
- YVL C.3 Limitation and Monitoring of Radioactive Releases from a Nuclear Facility, 15.3.2019. https://www.stuklex.fi/en/ohje/YVLC-3
- YVL B.5 Reactor Coolant Circuit of a Nuclear Power Plant, 2.9.2019. https://www.stuklex.fi/en/ohje/YVLB-5
- YVL guide A.9 Regulator reporting on the operation of a nuclear facility, 15.2.2019
- YVL C.7 Radiological monitoring of the environment of a nuclear facility, 19.12.2016

6.2. Discharge limits in effect

The annual dose constraint for an individual of the population arising from the normal operation of a nuclear power plant or as the result of an anticipated operational occurrence shall be 0.1 mSv (Nuclear Energy Degree 161/1988 22 b §). This is 1.7% of the average annual dose of 5.9 mSv caused by radiation for a person living in Finland. The limit is site-specific and applies to all nuclear installations on the site. Based on this limit, the Radiation and Nuclear Safety Authority (STUK) confirms the release limits for radionuclides during the normal operation of a nuclear power plant. According to Guide YVL A.6, the applicant and the licensee shall specify the release limits in the Operational Limits and Conditions of the plant and define operational practices. According to Guide YVL C.3, requirement 319: The release threshold requiring corrective action to be taken 3× the steady release rate consistent with the release limit (averaged over a maximum period of one month). Action limits for Loviisa (LO1&LO2) and OL3 are stricter than YVL C.3 guidance requires.

-LOVIISA (LO1 & LO2)

The discharge limits for radionuclides (except for tritium) from gaseous and liquid streams have been defined so that the annual dose of an individual in the population is no more than the prescribed annual dose limit of 0.1 mSv. Tritium production depends on the energy production of the plant unit, and the radiation dose calculated according to the separately set emission limit is clearly lower than the annual dose limit set for it.

I-131 eqv. and noble gases (Kr-87 eqv.) are used as performance indicators for air discharges, and the unit-specific action limit is determined and followed during the operation. Noble gas releases are calculated based on argon, xenon and krypton discharges. Annual discharge and action limits are presented in Table 13.

Table 13: Annual Discharge limits for Loviisa NPP site

Discharge	Effluent type	Discharge limit (GBq/y)	Action limit (Bq/s)
Airborne	Fission- and activation products (Kr-87 eqv.)	1.40E+07	55.56E+06 (stack) 1.75E+06 (turbine)
	Iodine (I-131 eqv.)	2.20E+02	861 (stack) 56 (turbine)
Water	Tritium	1.50E+05	2.31E+06
	Other fission- and activation products	8.90E+02	6.94E+03

According to the YVL C.3 the licensee must determine the target values for the annual radioactive releases of the nuclear facility and the radiation doses caused to the person representing the most exposed group in the population, which the licensee should aim to not exceed. These target values represent the continuous improvement of operations and the good operation of the plant and its personnel. The most meaningful radionuclides concerning Loviisa NPP units were chosen, and target values were determined for these radionuclides for each unit. Annual target values for the releases from Loviisa NPP are shown in Table 14. The calculated annual dose of an individual in the population is <0.001 mSv/y when the target release values of Table 14 are used.

Table 14: Annual target values of gaseous discharges for the Loviisa NPP site

Discharge	Effluent type	Unit	Target value (GBq/y)
Airborne	Xe-135	LO1	≤ 100
		LO2	≤ 100
	I-133	LO1	≤ 0.001
		LO2	≤ 0.01
	Fission- and activation products (gamma)	LO1 + LO2	≤ 0.05
	Tritium	LO1 + LO2	≤ 200
Water	Fission- and activation products (gamma)	Cs-treated water discharged is **NOT** performed	≤ 0.3
		Cs-treated water discharged is performed	≤ 2

-OLKILUOTO (OL3)

I-131 and noble gases (Kr-87 ekv.) are used as performance indicators for air discharges, and the steady release rate (OPR) is determined and followed for these nuclides during the operation. The OPR is based on the annual release limit and is calculated with averaging over a maximum period of one week. If OPR is reached, gaseous and liquid discharges will be followed on a nuclide-by-nuclide basis. The notation (1%) OPR/24 refers to the discharge of 1% of the annual release limit during the 24 hours. Noble gas releases are calculated based on discharges of argon, xenon and krypton. The annual release and action limits for gaseous discharges are presented in Table 15. OPR 1%/24h requires plant shutdown, which is stricter than YVL C3 guidance requires.

Table 15: Annual release, action and OPR limits for gaseous discharges for the OL3 plant

Radionuclide	Annual release limit for OL3 [GBq/y]	Action limit [Bq/s]	OPR [Bq/h]	Explanation
Carbon-14				No action limits, C-14 is power related nuclide, and no limits are given. Measured monthly.
Tritium	6.00E+04			No action limit, tritium is collected and measured monthly.
Noble gases	1.05E+06	1.16E+08	1.14E+11 and 4.16E+11 (OPR 1%/24h)	Kr-87 ekv. is used. Used OPR value is stricter than YVL requires.
Iodines	1.14E+01	1.16E+03	1.14E6 and 4.16E6 (OPR 1%/24h)	Limit for I-131. Other iodine isotopes are marginal in dose calculations. Used OPR value is stricter than YVL requires
Other radionuclides				No action limits, effect of aerosols is marginal.

According to Guide YVL C.3, requirement 518: The activity of tritium (H-3) and the total activity of alpha-emitting nuclides shall be determined from a composite sample representing the total release over a period of one month. Am-, Cm- and Pu- isotopes of alpha-emitting nuclides are analysed, and the threshold value of 1 kBq/m^3 is used. The annual release and action limits for liquid discharges are presented in Table 16.

Table 16: Annual release, action and OPR limits for liquid discharges of the OL3 plant

Radionuclide	Annual release limit for OL3 [GBq/y]	Action limit [Bq/s]	OPR [Bq/h]	Explanation
Tritium	6.00E+04	5.71E+06	6.85E+409	
Iodines				
Carbon 14				
Other fission or activation products (beta or gamma emitters)	4.00E+01	3.81E+03	4.57E+06	

6.3. Reporting obligations on discharge monitoring

Regulatory guide YVL A.9 requires the reporting of the releases and concentrations of radioactive substances in the environment to the Radiation and Nuclear Safety Authority (STUK). The following requirements are presented regarding the quarterly and annual reporting of radioactive discharges.

The quarterly environmental radiation safety report per each (plant) unit must include the following information on the releases of radioactive substances:

- The results from the continuous radioactive release monitoring systems;
- The measurement results from the release samples and the releases calculated on their basis;
- Sample-specific detection limits for the most significant radionuclides in the releases;
- The release times and the corresponding volume of air or water released into the environment;
- Any functional deviations of the measurement systems and their causes.

The quarterly report shall present a plant site-specific summary of the release information for the quarter in question and the current year: Releases into the atmosphere (noble gases, iodine, gamma-radiation particulate matter, tritium (H-3), carbon (C-14), alpha active substances). Releases into water (gamma-radiating fission and activation products, tritium, alpha active substances). The results shall be presented as graphical trends for a period of at least three years.

The annual report shall present the following information:

- A summary of the results to be reported and of the operation of each plant unit during the reporting year;

- Essential operating information concerning the releases of radioactive substances, such as times for annual outages and other longer outages, fuel failures, and the use of waste treatment and water removal systems;
- General descriptions of release routes, measurement equipment, sampling programme, analysis methods, and dispersion and dose calculations;
- An assessment of measurement precision and the operability of the measurement equipment;
- And an analysis of how the release limits and dose limits set for operation monitoring have been followed.

The releases of radioactive substances shall be reported for each plant unit, as well as in summary form for the entire plant site. The following items shall be presented in the report: release information for each radionuclide, broken down into release information for the quarter and the entire year for different release routes (into the air and into the cooling water); total release information, grouped as follows: Releases into the atmosphere (noble gases, iodine, gamma-radiating particulate matter, tritium (H-3), carbon-14 (C-14), alpha active substances); and releases into water (fission and activation products, tritium, alpha active substances). The results shall be presented as graphical trends for a period of at least three years. Air and water volumes are released from the plant unit into the environment through different release routes. The amount and composition of the releases shall be analysed in comparison to previous years. The reasons for significant changes shall be presented with explanations.

6.4. Compulsory technical requirements

An in-depth technical description of the liquid and gaseous discharge monitoring system is described in Guidance YVL C.6 radiation monitoring at a nuclear facility, 15.3.2019 and Guidance YVL C.3 Limitation and Monitoring of Radioactive Releases from a Nuclear Facility.

Continuous measurements are needed for noble gases, iodine, and nuclides in aerosol form from gaseous discharges. Laboratory analyses are needed for noble gases, iodine, and aerosol at least once a week; alfa and single remarkable nuclides (H-3, C-14) at least once a month; and for Sr-89, Sr-90 at least quarterly. Continuous measurement is needed for gamma activity from liquid discharges. Laboratory determinations are needed for gamma activity per release batch, especially for alpha and H-3 activity monthly and for Sr-89 and Sr-90 quarterly.

There is a need for redundancy in procedures for continuous measurements or laboratory analyses, and targets for detection limits in release flow are provided. All release pathways must be monitored, and the system shall comply with the single failure criterion, i.e. the system must be able to perform its safety function even in a situation where any single component of this system has failed.

The volumetric flow rate of gas within the significant points of release in all conditions must be able to be determined.

6.5. Main strengths and weaknesses of monitoring radioactive discharges

-LOVIISA (LO1 & LO2)

The emission reduction technologies used at the Loviisa power plant include the sorting, evaporation and filtration of radioactive water, as well as the filtration and delay of processed gases and exhaust air. The most important improvement made over time in terms of reducing radiation doses is the caesium-separation method for radioactive liquid introduced in 1990, thanks to which, the calculated radiation dose to the inhabitants of the environment has been significantly reduced.

The following projects have been implemented to reduce discharges:

1. The sample waters from the laboratory are returned to the process, which decreases the amount of liquid discharged through the laboratory tanks.
2. The fuel loading method was changed. According to computational estimates, the discharges of Ar-41 have decreased slightly with the change in the method of fuel loading, but this cannot be observed from the actual discharges.
3. Renewing sampling fume hoods and using the water locks for the discharged water from the analysers have reduced As-76 discharges to the air. Replacing the silver films with steel films and using the antimony-free seals have decreased the amount of silver and antimony radionuclides in the primary circuit.

-OLKILUOTO (OL3)

The liquid and gaseous discharge monitoring system and the emission reduction systems technologies of OL3 were designed according to the best available technique (BAT) of the time. The system is modern and fulfils the requirements according to Recommendation 2004/2/Euratom, and STUK Guidance YVL C.3. The equipment used for monitoring radioactive liquid and gaseous discharges is listed, and the regulatory body in Finland is reviewing the list regularly. In addition, the OL3 monitoring system covers continuous measurements for nuclide-based gamma activity and separation of C-14 discharges into inorganic and organic forms, and during the radiological emergency, the iodine discharges can be distinguished into inorganic and organic form. Sampling and continuous monitoring fulfil requirements of two-redundant trains.

6.6. Compliance with Recommendation 2004/2/Euratom

The detection limits are decided according to Recommendation 2004/2/Euratom, examples of Guidance YVL C.3, and the reached detection limits of Loviisa facility, are presented by nuclides in Table 17 for gaseous discharges and in Table 18 for liquid discharges. The liquid and gaseous discharge monitoring systems of Loviisa and OL3 fulfil the requirements according to Recommendation 2004/2/Euratom and examples of STUK guidance YVL C.3. Excluding Kr-85, which is based on beta-measurement after the decay of short-lived isotopes in Recommendation 2004/2/Euratom.

Table 17: The detection limit according to Recommendation 2004/2/Euratom, Guidance YVL C.3 (composed by STUK) and reached detection limits of Loviisa plant for gaseous discharges and reporting in RADD

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database	Highest value of detection limit of LOVIISA facility [Bq/m3]	Highest value of detection limit of OL3 unit [Bq/m3]	Detection limit in Recommendation 2004/2/Euratom [Bq/m3]	Examples of Detection limit in YVL C.3(4) [Bq/m3]
Kr-85	yes(6)	5.00E+03	1.67E+03	1.00E+04 (5)	1.00E+04
Xe-133	yes	1.00E+03	1.76E+01	1.00E+04	1.00E+04
Co-60	yes	1.00E-03	1.82E-04	1.00E-02	1.00E-03
Sr-90	yes	1.00E-04	?	2.00E-02	1.00E-04 (1)
S-35	N/A	N/A	N/A	N/A	N/A
Cs-137	yes	1.00E-03	2.10E-04	3.00E-02	1.00E-03
Pu-2390Pu240	yes	1.00E-03(2)	?	5.00E-03	1.00E-03 (2)
Am-241	yes	1.00E-04	?	5.00E-03	1.00E-04
I-131	yes	4.00E-03	1.05E-04	2.00E-02	4.00E-03 (3)
H-3	yes	1.00E+02	6.28E-01	1.00E+03	1.00E+02
C-14	yes	1.00E+01	2.64E-01	1.00E+01	1.00E+01

(1) Combined activity of Sr-89 and Sr-90
(2) Combined activity of alfa nuclides
(3) In laboratory analyses and 2.00E+00 for continuous measurements <1h
(4) Examples of detection limits that can be achieved or beaten According to Guidance YVL C.3

(5) Can normally be obtained by beta-measurement after decay of short-lived isotopes

(6) Kr-85 gaseous discharges have not been reported since 2015, and Pu239+Pu240 or Am-241 (gaseous and liquid discharges) are not reported since 2012.

Table 18: The detection limit according to Recommendation 2004/2/Euratom, Guidance YVL C.3 (composed by STUK) and reached detection limits of Loviisa plant by nuclides for liquid discharges

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD datebase	Highest value of detection limit of LO1&LO2 units [Bq/m3]	Highest value of detection limit of OL3 unit [Bq/m3]	Detection limit in Recommendation 2004/2/Euratom [Bq/m3]	Examples of detection limit in YVL C.3(3) [Bq/m3]
Co-60	yes	1.00E+03	5.71E+01	1.00E+04	1.00E+03
Sr-90	yes	2.00E+02 (1)	1.76E+01	1.00E+03	2.00E+02 (1)
S-35	N/A	N/A	N/A	N/A	N/A
Cs-137	yes	1.00E+03	4.98+01	1.00E+04	1.00E+03
Pu-239 Pu240	Yes (4)	6.00E+02 (2)		6.00E+03	1.00E+03 (2)
Am-241	Yes (4)	-		5.00E+01	1.00E+01
H-3	yes	5.00E+04	2.64E+04	1.00E+05	5.00E+04

(1) Combined activity of Sr-89 and Sr-90

(2) Combined activity of alfa nuclides

(3) Examples of detection limits that can be achieved or beaten According to Guidance YVL C.3

(4) Pu239+Pu240 or Am-241 have not been reported since 2012 (gaseous and liquid discharges)

7. Lithuania

In Lithuania, the Ignalina nuclear power plant (INPP) was visited, having two defueled RBMK-1500 reactors and is currently undergoing decommissioning. The discharge report was done based on the visit, materials, discussion, and comments from the VATESI and INPP personnel.

7.1. Regulatory basis for controls on radioactive discharges

List of the national laws and regulations of Lithuania related to radioactive discharge monitoring are listed below.

The Framework of the nuclear and radiation protection regime in Lithuania is based on seven Laws:

- Law on radiation protection (No VIII-1019,1999, last amended 2018)
- Law on nuclear safety (No XI-1539, 2011, last amended in 2021-05)
- Law on the management of radioactive waste (No. XIII-1285, last amended in 2018)
- Law on nuclear energy (No. I-1613, last amended 2022-07)
- Law on Environmental Monitoring, No. X-595/VIII -529 dated May 4, 2006. State News, 2006, No. 57-2025 (last amended 2020).
- Law on Environmental Protection (No XII-1718, last amended 14 May 2015)
- Law on Civil Protection of the Republic of Lithuania (No VIII-971, last amended 22 December 2009)

Besides these laws, discharge monitoring is regulated by following national rules and regulations:

- The Rules of decommissioning of the facilities using sources of ionizing radiation (by the order No. V-712, 2003)
- The Nuclear Safety Requirements BSR-1.9.1-2017 "Standards and Requirements for the Plan for the Release of Radionuclides from Nuclear Power Facilities" regulates the limitation of the release of radionuclides from nuclear facilities into the environment, establishes standards of the release of radionuclides from NI and the requirements for the plan on the release of the radionuclides and the control of the release of the radionuclides. https://www.e-tar.lt/portal/lt/legalAct/TAR.FC5AAF914979/asr
- Lithuanian Hygiene Standard HN 73:2018 "Basic Radiation Safety Standards", 2001
- The requirements of radiological monitoring for operators are set out in the order of the minister for health "Order on the Approval of the description of the procedure for radiological environmental monitoring of economic entities" No. V-3028 https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/18583f62495011ebb394e1efb98d3e67?jfwid

- Regulation on Performance of Environment Monitoring of Economy Entities. Approved by the Minister of Environment Ordinance No. D1-628 dated December 12, 2004. State News, 2004, No. 181-6712.
- Nuclear safety requirements BSR-2.1.2-2010 " General Requirements for Ensuring Safety at Nuclear Power Plants with Type RBMK-1500 Reactors ", DVSnd-0048-1
- Nuclear safety requirements BSR-1.9.3-2016 "Radiation protection in Nuclear Installations", DVSnd-0048-32.
- Nuclear safety requirements BSR-1.5.1-2019 "Decommissioning of nuclear Installations", DVSnd-0048-24.
- Nuclear safety requirements BSR-1.6.1-2019 "Physical safety of nuclear power facilities, sites of nuclear power facilities, nuclear and nuclear fuel cycle materials", DVSnd-0048-16.
- Nuclear Safety Requirements BSR-1.3.1-2020 "Enforcement of Emergency Preparedness in Nuclear facilities", No. 22.3-Vilnius, 2020.

The main legal act of Lithuania regarding monitoring is the Law on environmental monitoring which specifies the content, structure, implementation, rights, and duties as well as the responsibility of the entities participating in the process of environmental monitoring.

The main regulation related to radioactive discharges is BSR-1.9.1-2017 which sets the standard of release and requirements for release plans from nuclear facilities. It also sets the specific requirements and controls for the plant to release radionuclides into the environment, supervision of release performed by the operator, and standard content of the plan of release. It says that to protect the population and environment in the normal operation of the nuclear facility, the annual effective dose of a representative person will not exceed the dose constraint. Also, if multiple nuclear facilities affect the person, the same constraints apply. The radionuclide limits are set so that the total release of radionuclides and direct external ionising radiation shall not exceed the dose constraint. The activity limits are calculated considering both internal and external exposure doses and the radionuclides released into water and air through all possible pathways that are dangerous.

7.2. Discharge limits in effect

The Lithuanian Hygiene standard HN73:2018 sets the dose constraints for INPP, and says that for members of the public, due to the release of radioactive materials to the environment from the nuclear facility or directly from the nuclear facility, the effective dose is 0.2 mSv/year. This standard also sets the annual dose limits for workers, apprentices, students, and members of the public. The values are calculated based on BSR-1.9.1-2017. The activity limits and planned emissions in gaseous and liquid discharges per year for INPP are outlined in Table 19 and Table 20.

Table 19: Gaseous Discharge limits

Radionuclide	Activity limit Bq/year	Planned emission Bq/year
Noble gases	2.78E+13	2.31E+12
Aerosols	2.90E+09	2.41E+8
H-3	1.01E+13	8.42E+11
C-14	1.42E+11	1.18E+10
I-131	Na.	Na.
Total	3.81E+13	3.16E+12

Table 20: Radionuclide release limits for liquid discharge

Radionuclide	Activity Limit, Bq/year	Planned emission, Bq/year
Mn-54	1.15E+08	5.76E+6
Co-60	4.64E+08	2.32E+7
Nb-94	1.49E+06	7.46E+4
Sr-90	1.73E+07	8.65E+5
Cs-134	1.21E+06	6.06E+4
Cs-137	3.00E+09	1.5E+8
H-3	1.50E+13	7.51E+11
Total alfa*	8.00E+05	4E+4
Total values	1.50E+13	7.51E+11

*Radionuclides U-235, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Am-241 and Cm-244

7.3. Reporting obligations on discharge monitoring

BSR-1.9.1-2017 sets the control of radionuclide releases into the environment, supervision of release control performed by the operator and tells the standard content of the plan of radionuclide release into the environment. The operator must establish a plan for the release of radionuclides into the environment.

The operator needs to monitor the pollution caused by radionuclides under the provisions of the procedure established by the Law on Environmental Monitoring of the Republic of Lithuania. The data of pollution monitoring is collected and preserved according to the procedure established by the Law on Document and Archives.
If an activity increase is identified, the operator shall determine the reasons and:

"If release per day exceeds 1% of annual activity – shall inform VATESI, the Environmental Protection Agency (EPA) and the Ministry of Health (MoH) within three business days and submit a forecast of pollution indication reasons and actions taken to reduce it. If release per month exceeds 25% of annual activity limits –they shall take measures to reduce the release, and within five business days shall submit information on the reasons and the measures taken to the aforementioned agencies. "

After identification that the activity limits of the radionuclides indicated in the plan are exceeded, or detection of activities not indicated in the plan, the operator shall:

"Analyse reasons and consequences, take measures to eliminate the causes, and within five business days after the identification shall inform VATESI, the Environmental Protection Agency and the Ministry of Health about the reasons, their elimination, and preventive measures being taken or planned. VATESI then sets a deadline for the elimination of the causes.

At the beginning of the following month (not later than ten working days), the operator shall submit to VATESI, the EPA, and the MoH, data regarding activities of the release of radionuclides per month, with the exception H-13 and C-14, which are submitted every three months."

The annual report regarding the activities of the release of radionuclides released into the environment is submitted by the 1st of April of the following calendar year to VATESI and the MoH. In that report, the following shall be indicated:

- The activity of radionuclides released to air and water (monthly) and total annual activity;
- Comparison of the activity of the released radionuclides and the activity limits;
- The trends and analysis of pollution;
- Estimated effective doses for the representative person caused by radionuclide releases per year);
- The reasons for unplanned activities, the analysis of the releases, and any unidentified nuclides not indicated in the Plan.

The assumptions, parameters, and values used in identifying and selecting a representative person shall be reviewed and evaluated at least once every ten years. Every ten years, the discharge limits also must be reviewed.

In accordance with the Law on Nuclear Safety, discharge limits should be reviewed if there are new discharged radionuclides, pathways, media, points of discharge, or a case where the exposure dose of the members of critical groups of the population exceeds or might exceed the dose constraint. Now that the Ignalina NPP is under decommissioning, to meet the regulations previously mentioned, discharge limits were reviewed often, and changed three times within the last ten years.

7.4. Compulsory technical requirements

According to BSR-1.9.1-2017, the operator shall ensure the control of the release of radionuclides to the environment by performing pollution monitoring. Pollution monitoring of the NF is executed under provisions of the procedure established by the Law on Environmental Monitoring of the Republic of Lithuania.

The laboratories performing measurements and analysis of the pollutants discharged to the environment for air, water, and soil, must hold authorisations for the performance of these measurements and analysis must be accredited in accordance with the procedure laid down by the regulations. The procedure for issuing authorisations for the performance of measurements and analysis of the pollutants shall be decided by the Ministry of Environment.

The regulations on the environmental monitoring by operators determines that environmental radiological monitoring must be carried out by the operator who designs, constructs or operates nuclear facilities, decommissions the NF, and carries out the supervision of closed repositories of radioactive waste. According to this regulation:

"The monitoring of NF shall be carried out in accordance with the environmental radiological monitoring programme set up by the operator, and coordinated with the EPA covering the monitoring of discharges and the environmental impact. A review of the programme is done every five years."

The detection limits of the devices measuring radioactivity and their requirements are set by Recommendation 2004/2/Euratom.

7.5. Main strengths and weaknesses of monitoring radioactive discharges

The Ignalina NPP operator has a laboratory research department having gamma, alpha, and beta measurement devices for gaseous and liquid samples, and is evaluated according to ISO 17025 standards. The Ignalina facilities also have an Inspection and Calibration Laboratory, which is accredited as a control institution that performs the inspection of pressure, temperature, electrical quantities, and ionizing radiation measuring devices.

Special components and systems are included in the plant for the protection of the facility and its environment from radiation. The following systems are used for radiation protection and monitoring:

- Control and protection system
- Fuel cladding and reactor channel integrity monitoring system
- Reactor emergency core cooling system
- Accident confinement system
- Plant liquid radioactive gas-aerosol cleaning, removal or storage system
- Plant and environment radiation protection monitoring system
- Gas-aerosol and liquid monitoring system.

In INPP, special filters are used to absorb radioactive aerosols in the gaseous effluent to prevent it from entering the atmosphere. A circular water supply system is used at the INPP. Equipment for automated monitoring of radiation protection has been installed at the INPP. There is also a two-stage purification system in which the treated gas and aerosol is released into the atmosphere through a 150 m ventilation stack. In stage one, the delay chamber is used to decrease concentration when the radiation level increases, then in stage two, dynamic sorption method is used with the concentration reduction device to clean gases and lower their concentration.

The radiation levels of gases, aerosols, and radioactive liquid released to the environment are continuously being monitored by using automatic equipment of the radiation control system. The INPP's environment radiation monitoring service is equipped with state-of-the-art instrumentation. The INPP laboratory has spectrometers that enable them to measure the sampled radioactivity.

Currently, the stack flow measurement equipment is in the process of being replaced with modern and more accurate versions. The existing equipment is designed for an operating power unit and large volumes of exhaust air.

Ignalina NPP has their own solid waste treatment facility and radioactive liquid treatment facility, which helps safely handle contaminated materials.

7.6. Compliance with Recommendation 2004/2/Euratom

The detection limits, according to Recommendation 2004/2/Euratom, and the reached detection limits of the INPP facility for each nuclide are presented in Table 21 for gaseous discharges and in Table 22 for liquid discharges. The liquid and gaseous discharge monitoring systems of INPP fulfil the requirements according to Recommendation 2004/2/Euratom. In addition, the detection limits are for all nuclides are lower than what is required in Recommendation 2004/2/Euratom. Some of the nuclides mentioned in the Recommendation were not found (Note: Once the Ignalina NPPr plant site obtains the Decommissioning Licence for both

Units, after defueling, it will not have any formal obligation to follow Recommendation 2004/2/Euratom requirements.'').

Table 21: Compliance with Recommendation 2004/2/Euratom for key radionuclides in gaseous discharge

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database	Highest value of detection limit of facility [Bq/m3]	Detection limit in Recommendation [Bq/m3]
Kr-85	No	Not measured	1.00E+04
Co-60	Yes	7.00E-03	3.00E-02
Sr-90	Yes	2.00E-05	2.00E-02
Cs-137	Yes	5.60E-03	3.00E-02
Pu-239+Pu-240	No	Not measured	1.00E-03
Am-241	No	Not measured	1.00E-03
I-131	No	Not measured	2.00E+00
H-3	Yes	7.10E-01	1.00E+03
C-14	Yes	5.10E-01	1.00E+01
Total-alpha	Yes	1.10E-06	1.00E-02

Table 22: Compliance with Recommendation 2004/2/Euratom for key radionuclides in liquid discharge

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database	Highest value of detection limit achieved of facility [Bq/m3]	Detection limit in Recommendation [Bq/m3]
Co-60	Yes	2.3	1.00E+04
Sr-90	Yes	100	1.00E+03
Cs-137	Yes	2.2	1.00E+04
Pu-239+Pu-240	Yes	0.2	6.00E+03
Am-241	Not measured	-	5.00E+01
C-14	No	630.0	-
other nuclides			-
H-3	Yes	1300.0	1.00E+05
Total-alpha	Yes	10.0	1.00E+03

8. Czech Republic

The Temelin NPP with two PWR reactors VVER 1000 type owned by CEZ Group JVC where the State is a main stakeholder (with a 70% share), and the installed capacity (2 x 1055 MW) was a subject of this study in the Czech Republic.

8.1. Regulatory basis for controls on radioactive discharges

Based on Act No. 263/2016 Coll., the Atomic Act, Act No. 19/1997 Coll., and Act No. 281/2002 Coll., the State Office for Nuclear Safety (SUJB) is the central authority of the state administration responsible for the exercise of regulatory activities in the peaceful utilisation of nuclear energy and ionizing radiation.

In accordance with Act No. 263/2016 Coll. (Atomic Act), the SUJB shall create the National Monitoring Programme. The purpose of the National Monitoring Programme (NMP) is to determine the extent of the radiation monitoring on the territory of the Czech Republic, and clarify the requirements for the transfer of data to the Data Centre of the State Office for Nuclear Safety, which includes data formats and data interfaces. Under the NMP, monitoring shall be carried out by the SUJB, administrative authorities referred to in the Atomic Act, and other persons referred to in the NMP.

The main objectives of radiation monitoring is to ensure the following:

- Radiation monitoring on the territory of the Czech Republic for all exposure situations;
- Collection and management of data and related information (including historical data), evaluation, and publication of data about the radiation situation.

Data from radiation monitoring is used to evaluate the exposure of the population and, in an emergency exposure situation, is used to specify the radiation level in the affected area and subsequently implement, clarify, or cancel protective measures.

The SUJB shall inform the Government of the Czech Republic, the European Commission, and the general public about the results of the monitoring.

Other legislative documents giving the framework for control of radioactive discharges from Temelin NPP are:

- Decree No. 359/2016 Coll., on details of ensuring radiation extraordinary event management.
- Decree No. 360/2016 Coll., on radiation situation monitoring.
- Decision 24102/2017, which allows the release of radioactive substance from the Temelin Nuclear Power Plant in the form of discharges into the air from the ventilation chimneys of the production units, from the ventilation chimney of the auxiliary building, and from the PSA system.

- Decision 32016/2021 which allows the release of radioactive substance from the Temelin Nuclear Power Plant workplace in the form of discharges into the waterways - the Vltava River in the Korensko profile.

8.2. Discharge limits in effect

According to Czech national legislation - Atomic Act, the dose constraint is 250 μSv per calendar year (200 μSv for air and 50 μSv for water) from radioactive discharges.

The licenses issued for Temelin NPP by SUJB states that the two authorized limits for liquid and gaseous discharges, i.e., the annual effective dose received by a representative person from the population caused by radioactive discharges to surface waters and air during the operation of the NPP, are as follows:

- effective dose (by calendar year) is 40 μSv/year for discharges into the air;
- effective dose (by calendar year) is 3 μSv/year for discharges into surface waters.

For the purpose of monitoring gaseous discharges, the units Bq/m^3 and Bq (kBq, MBq, GBq) are used for the total activity. The calculation of the effective dose from gaseous discharges is carried out using the regulatory conversion factors listed in the Decision of the SUJB No. SUJB/RCCB/24102/2017.

For the monitoring purpose of liquid discharges, the units Bq/l and Bq (kBq, MBq, GBq) are used for the total activities. The calculation of effective dose from liquid discharges is carried out using the regulatory conversion factors listed in the Decision of the SUJB No. SUJB/OROPC/26161/2009.

8.3. Reporting obligations on discharge monitoring

According to SUJB Decree 360/2016 Coll. and the National Monitoring Programme, the operator is required to report the monitoring results.

Decree 360/2016 Coll. establishes the *recording levels* (the level of the lowest detectable value of the measured quantity) and the *investigation levels* (upper limits of normally occurring values of the measured quantity), which should be recorded on a daily basis.

In accordance the Atomic Act and Decree 360/2016 Coll., the operator should provide reports about the radiation situation in the Temelin NPP location quarterly and annually, and report about discharge monitoring monthly.

The operator should also inform the Regulatory Authority about any deviation in the monitoring of discharges on a daily, monthly, quarterly, and annual basis. In addition to event reports, the operator should provide the investigation protocols.

Authorization inspectors check the operator's reports on an ongoing basis; daily, monthly, quarterly, annual, and event reports are subject to inspection by an annual specialized inspection on discharges.

8.4. Compulsory technical requirements

According to the Atomic Act, anyone who uses nuclear energy or performs activities in exposure situations shall continuously and comprehensively evaluate compliance with the principles of the peaceful uses of nuclear energy and ionising radiation (from the perspective of the present level of science and technology), and ensure that the results of the evaluation are applied in practice. Should the National Authority inspector find during a discharge monitoring inspection that the operator uses outdated technology, the inspector may request remedy measures due to this requirement.

The monitoring of discharges is within the scope proposed in the CEZ management document 0TS626 "ETE discharge monitoring programme", amended by Temelin's operating regulation 0TS626DZ01. This document is approved by SUJB decision No. SUJB/RCCB/287/2020 dated 07.01.2020.

The detection limits (Bq/m^3) for liquid and gaseous discharge monitoring equipment are established by Decree No. 360/2016 Coll. on radiation situation monitoring, Appendix No. 3 Table No. 4 (overtaken from Recommendation 2004/2/Euratom). The Regulatory Authority does not set any other detection limits for equipment for monitoring liquid and gaseous discharges. The requirements according to Decree 360/2016 Coll. and the National Monitoring Programme are applied to these devices.

8.5. Main strengths and weaknesses of monitoring radioactive discharges

The effluents generated are well known (location of release, type of radionuclide, expected quantities, etc.), which allows Temelin to adapt its monitoring efficiently.

The detection equipment used is fit for the radionuclides being monitored. Online monitoring is used with redundant sampling lines, and detectors in case of failure. To obtain a representative sample of the gaseous discharges, an isokinetic sampling nozzle with multiple inputs is installed in the ventilation stack. The system also includes a device for measuring the value of the average flow in the stack.

The Temelin NPP chemistry laboratory has accreditation of ASLAB (Czech Centre for the assessment of laboratories) according to CSN EN ISO/IEC 17025:2017. The measurement results are subjected to international comparison as a guarantee of quality. The laboratories participate every year in international laboratory comparison tests organised by IAEA.

The chemistry laboratory uses database computer information system CHEMIS. This system ensures complete management of all laboratory activities, such as registration of samples, calculating the balance of discharges, and reporting. The

CHEMIS can be easily upgraded according to any legislative changes.

Even though Temelin NPP's reactors are not a gas-cooled-type, key noble gas nuclide Xe-133 is monitored and reported in daily and yearly balances. Monitoring of noble gases are provided by continuous beta-measurements in online noble gases monitors, while detection limits and yearly balances are calculated on the basis of gamma-spectrometry of high-pressurized sample collecting for one week.

In addition to key nuclide monitoring as established in Recommendation 2004/2/Euratom, Temelin determines radiocarbon C-14 in liquid discharges using a method developed by the Czech Academy of Science.

It should be mentioned that there is not a periodical discharge limit review to ensure the requirements are still "fit for purpose" in the Czech Republic. The limits are reviewed by the Regulatory Authority, depending on changes in the input parameters and refinement of computational algorithms, keeping up with the best available techniques.

8.6. Compliance with Recommendation 2004/2/Euratom

The Temelin NPP fulfils Recommendation 2004/2/Euratom for monitoring all established key radionuclides, except S-35 which is related to gas-cooled-type reactors. These radionuclides are also reported in the EC RADD.

The value of the measurements achieved at the facility is very good, as the values are generally many times smaller than the limits in Recommendation 2004/2/Euratom.

The Temelin NPP monitors both organic and inorganic forms of carbon C-14, but they report a combined amount. Similarly, they report only the combined total for aerosol and gaseous forms of iodine I-131.

In addition to Recommendation 2004/2/Euratom, noble gas nuclides Kr-85 and Xe-133 are monitored and reported on a daily and yearly basis.

Table 23 presents the result of a gap analysis for the key radionuclides in gaseous discharge that should be monitored according to Recommendation 2004/2/Euratom, and if they are reported in the EC RADD.

Table 23: Compliance with Recommendation 2004/2/Euratom for key radionuclides in gaseous discharge, Temelin NPP

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database?	Highest value of the detection limit achieved at Facility (Bq/m^3)	Detection limit in Recommendation (Bq/m^3)
Kr-85	Yes	1,00E+00	1,00E+04
Xe-133	Yes	1,90E+01	1,00E+04
Co-60	Yes	1,31E-05	1,00E-02
Sr-90	Yes	1,87E-06	2,00E-02
S-35	N/A	N/A	1,00E+01
Cs-137	Yes	1,23E-05	3,00E-02
Pu-239+Pu-240	Yes	1,61E-06	5,00E-03
Am-241	Yes	1,29E-06	5,00E-03
I-131	Yes	2,46E-04	2,00E-02
H-3	Yes	1,00E-01	1,00E+03
C-14	Yes	1,00E-01	1,00E+01

Table 24 presents the result of a gap analysis for the key radionuclides in liquid discharge that should be monitored according to Recommendation 2004/2/Euratom and if they are reported in the EC RADD.

Table 24: Compliance with Recommendation 2004/2/Euratom for key radionuclides in liquid discharge, Temelin NPP

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database?	Highest value of the detection limit achieved at Facility (Bq/m^3)	Detection limit in Recommendation (Bq/m^3)
H-3	Yes	1,00E+04	1,00E+05
S-35	N/A	N/A	3,00E+04
Co-60	Yes	9,41E+02	1,00E+04
Sr-90	Yes	2,07E+01	1,00E+03
Cs-137	Yes	1,31E+03	1,00E+04
Pu-239+Pu-240	Yes	1,49E+01	6,00E+03
Am-241	Yes	1,59E+01	5,00E+01

9. Slovak Republic

The Mochovce NPP, with four PWR reactors (VVER 440 type) and installed up-rated capacity (2 x 505 MW) were subjects of this study in the Slovak Republic.

The owners of the Mochovce site are the state-owned organization JVC Slovenske elektrarne a.s., an Italian utility company Enel owning 33%, and a Czech energy group named EPH owning 33% of the NPP.

9.1. Regulatory basis for controls on radioactive discharges

In the field of radiation protection, the Public Health Authority of Slovak Republic (PHA SR) performs both permanent and continuous state supervision of radiation protection in nuclear installations, and workplaces where activities are performed.

The Public Health Authority of Slovak Republic provides the following main activities:

1. Carries out state supervision in the field of radiation protection;
2. Determines nuclear facilities conditions and authorised limits;
3. Controls authorised limits and conditions;
4. Permits performance of activity leading to irradiation;
5. Determines the reference levels for optimization of radiation protection in an emergency exposure situation.

In the frame of radiation protection activities, PHA SR ensures radiation control of gaseous and liquid discharges.

The Slovak Republic's main legislative documents giving the framework for radioactive discharge are listed below:

- Act No. 87/2018 Coll. on radiation protection
- MoH SR Decree No. 99/2018 on ensuring radiation protection
- MoH SR Decree No. 96/2018 laying down the details of activity of radiation monitoring network
- Public Health Authority of the Slovak Republic decision No. OOZPŽ/4603/2019 from 15.10.2019
- Governmental order of the Slovak Republic No. 269/2010 Coll. on "requirements on good water"
- Regional District Office in Nitra decision No. OU-NR-OSZP2-2021/010916, 16th March 2021 specified values of indicators of in radioactive water discharged into the river Hron, and also specified the reference monitoring point

  Public Health Authority of the Slovak Republic decision No. 8182/2021 from 30.08.2021

9.2. Discharge limits in effect

According to Slovak national legislation, Act No. 87/2018 Coll. on radiation protection, radioactive substances can be discharged from nuclear facilities into the air and surface water if it is provided that effective doses in the relevant critical population group will not exceed 250 µSv/year (calendar year) due to these discharges.

The license issued for the organization Slovenske elektrarne a.s. by the Public Health Authority in Bratislava, under Decision No. OOZPZ/4603/2019, states the basic authorised radiological limit for the annual effective dose received by a representative person from the population caused by radioactive discharges to surface waters and air during the operation of the NPP will not exceed 0,075 mSv, **specifically**:

- Effective dose 0,070 mSv/year (calendar year) for discharges into the air
- Effective dose 0,005 mSv/year (calendar year) for discharges into surface waters

The units used for discharge limits are:

- The rates of the individual or grouped radionuclides released TBq/year
- In terms of concentration Bq/m^3
- Dose to the critical group or representative person mSv

9.3. Reporting obligations on discharge monitoring

The reporting obligations on discharge monitoring are established by Decision No. OOZPZ/4603/2019 dated 15.10.2019 of the PHA SR.
Based on this decision, as required in condition 17, the operator must inform the National Authority about any deviation immediately. The immediate announcement is made by e-mail, and the final written report about the deviation is sent by post.

According to the Decision No. OOZPZ/4603/2019, Mochovce NPP is obliged to compare the activity of radioactive substances released during the year with the established annual reference levels (previously referred to as guideline values) and report on the radioactivity of discharged substances.

The summary report about the results of monitoring of radioactive discharges and monitoring of radioactivity around the Mochovce NPP is issued (on a time period of every six months, and annually) and sent to the PHA SR and the regulatory authority.

In addition, quarterly and annual summary reports about the radioactive discharges are issued and sent to the Nuclear Safety Committee.

9.4. Compulsory technical requirements

Generally, the Decision No. OOZPZ/4603/2019, issued by the National Authority (Public Health Authority of the Slovak Republic), as well as the ALARA approach based on operational experience, are the basis for technical requirements for discharge monitoring equipment.

This Decision establishes a set of requirements for the operator:

- List of radionuclides to be monitored in gaseous and liquid discharges
- Their day and annual reference levels
- Scope and places of continuous discharge monitoring
- Requirements for monitoring results reporting and archiving

The operator should also provide two equivalent continuous measuring devices for any of the parameters where an annual reference level is set, with the exception of tritium released from administrative control into the environment. At any time, at least one of the two devices must be in operation.

The Regulatory Authority does not set any other requirements or detection limits for equipment for monitoring liquid and gaseous discharges.

9.5. Main strengths and weaknesses of monitoring radioactive discharges

The effluents generated are well known (location of release, type of radionuclide, expected quantities, etc.), which allows Mochovce to adapt its monitoring efficiently.

The detection equipment used is acceptable for the radionuclides being monitored. Online monitoring is equipped with redundant sampling lines and detectors in case of failure. To obtain a representative sample of the gaseous discharges, an isokinetic sampling nozzle with multiple inputs is installed in the ventilation stack. The system also includes a device for measuring the value of the average flow to the stack.

Some modifications in the measurement of gaseous discharge in ventilation stack VK2 were completed, so more up-to-date equipment is used.

Mochovce NPP laboratories are not accredited but participate every year in international laboratory comparison tests organised by IAEA. Participation in comparison programs gives a certain guarantee that measurements are accurate. These comparison programs are a means of evaluating the facility monitoring capacities, and corrective measures can be taken if results recieved are non-satisfactory.

The module "Laboratory measurements and discharges" was internally developed within the SAP Nuclear database system for the Laboratory department. This module is used for the complete management of all laboratory activities, such as the registration of samples, calculating the balance of discharges, and reporting. This software module can be easily upgraded according to any legislative changes.

Mochovce NPP's reactors are not gas-cooled-type reactors, but despite this, key noble gas nuclides Kr-85 and Xe-133 are monitored and reported. Online monitoring of noble gases is provided by continuous beta-measurements in noble gases monitors, while detection limits and the yearly total is calculated on the basis of gamma-spectrometry on high-pressurized sample collection for one week.

According to Public Health Authority, there is a need for better monitoring methods/techniques of radiocarbon C-14. Also, continuous monitoring of radioactive discharges on the rivers Vah and Hron by PHA would be more effective than once per month, and continuous parallel monitoring of iodine and noble gases is required.

It should be mentioned that there is no periodical discharge limit review to ensure the limits are still "fit for purpose" in the Slovak Republic. The limits are reviewed by the Regulatory Authority irregularly, depending on changes in the input parameters and refinement of computational algorithms, maintaining the best available techniques.

9.6. Compliance with Recommendation 2004/2/Euratom

The Mochovce NPP fulfils Recommendation 2004/2/Euratom for monitoring all established key radionuclides, with the exception of S-35 which is related to gas-cooled-type reactors. These radionuclides are also reported in the EC RADD.

The highest value of the measurements achieved at the facility is very good, and generally many times smaller than the ones in Recommendation 2004/2/Euratom.

The Mochovce NPP, in accordance with Article 8(d) states of Recommendation 2004/2/Euratom, separately reports discharges of:

- organic and inorganic forms of carbon C-14,
- chemical/physical form of tritium,
- aerosol and gaseous forms of iodine I-131.

In addition to Recommendation 2004/2/Euratom, noble gas nuclides Kr-85 and Xe-133 are monitored and reported on a daily and yearly basis.

Table 25 presents the result of a gap analysis for the key radionuclides in gaseous discharge that should be monitored according to Recommendation 2004/2/Euratom, and if they are reported in the EC RADD.

Table 25: Compliance with Recommendation 2004/2/Euratom for key radionuclides in gaseous discharge, Mochovce NPP

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database?	Highest value of the detection limit achieved at Facility (Bq/m^3)	Detection limit in Recommendation (Bq/m^3)
Kr-85	Yes	5,90E+02	1,00E+04
Xe-133	Yes	1,81E+01	1,00E+04
Co-60	Yes	4,01E-05	1,00E-02
Sr-90	Yes	1,39E-08	2,00E-02
S-35	N/A	N/A	1,00E+01
Cs-137	Yes	5,74E-06	3,00E-02
Pu-239+Pu-240	Yes	1,13E-08	5,00E-03
Am-241	Yes	7,79E-08	5,00E-03
I-131	Yes	1,38E-05	2,00E-02
H-3	Yes	7,25E+01	1,00E+03
C-14	Yes	7,10E-02	1,00E+01

Table 26 presents the result of a gap analysis for the key radionuclides in liquid discharge that should be monitored according to Recommendation 2004/2/Euratom, and if they are reported in the EC RADD.

Table 26:Compliance with Recommendation 2004/2/Euratom for key radionuclides in liquid discharge, Mochovce NPP

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database?	Highest value of the detection limit achieved at Facility (Bq/m^3)	Detection limit in Recommendation (Bq/m^3)
H-3	Yes	1,80E+04	1,00E+05
S-35	N/A	N/A	3,00E+04
Co-60	Yes	7,61E-02	1,00E+04
Sr-90	Yes	5,06E-05	1,00E+03
Cs-137	Yes	8,18E-02	1,00E+04
Pu-239+Pu-240	Yes	1,58E-05	6,00E+03
Am-241	Yes	1,54E-05	5,00E+01

10. Romania

Cernavoda Nuclear Power Plant (NPP), the only Canadian Deuterium Uranium (CANDU) reactor in Europe, is located in the south-east of Romania and was a subject of this study in Romania.

Cernavoda NPP has two power units, each with an installed power of approx. 700 MWe and ensures about 20% of Romania's energy demand. The Cernavoda NPP is a division (no legal entity) of the Romanian national company SN "Nuclearelectrica" SA.

10.1. Regulatory basis for controls on radioactive discharges

The National Commission for Nuclear Activities Control (CNCAN) is the competent national nuclear authority responsible for the regulation, licensing, and control in nuclear field for all nuclear activities and installations in the Romanian territory.

Law No. 111/1996 on the safe deployment, regulation, licensing, and control of nuclear activities empowers the CNCAN to issue mandatory regulations, authorize licenses for nuclear installations and activities, perform assessments and inspections to verify compliance with the nuclear safety requirements, and to take any necessary enforcement actions.

CNCAN approves the Cernavoda NPP monitoring program for liquid and gaseous discharge. According to the regulatory requirements, the licensee must send monthly and quarterly reports on the liquid and gaseous discharges to CNCAN.

CNCAN has imposed radiation dose limits that can be received by persons from the population and has approved methodology for establishing the derived emission limits (DELs) for Cernavoda NPP.

CNCAN establishes derived emission limits (DELs) to ensure effective control of emissions, expressed by the amount of radionuclides that can be released from their respective sources, so that the exposure of a representative individual from the critical group does not exceed a dose constraint.

The following is the current regulations that are applicable for the liquid and gaseous discharges monitoring in Romania:

- NSR-21 Norms on the monitoring of radioactive emissions from nuclear and radiological installations – Order no. 276/2005,
- NSR-22 Norms for the monitoring of environmental radioactivity in the vicinity of a nuclear or radiological facility – Order no. 275/2005,
- NSR-23 Norms on dispersion calculation of radioactive effluents discharged in the environment by nuclear installations – Order no. 360/2004,
- NDR-04 Norms on the limiting of effluents release into environment – Order 221/2005,
- NMC series Quality management systems norms, NMC series, NMC01-

NMC13 (2003).

- Norms regarding the basic requirements of radiological security – Order Min. Health/ Min. National Education / CNCAN no. 752/3.978/136/2018.

10.2. Discharge limits in effect

According to the dedicated Cernavoda NPP procedure RD-01364-RP004 – Radioactive Materials Control Process, DELs are defined as the upper limit for the release of a particular radionuclide in effluents of both gaseous and liquid origins. This limit is obtained from observing the regulated limits from the equivalent doses calculated via mathematical models of all significant exposure pathways for an individual in the critical group. The DEL is set in such a way that the annual dose limit will not be exceeded for any of the people in the critical population.

The measuring unit in which discharge limits are expressed in the national regulations are:

- The rates of the individual or grouped radionuclides released (GBq/year, MBq/day)
- In terms of concentration (Bq/m^3)
- Dose to the critical group or representative person (mSv)

CNCAN has established limits for discharges released into the atmosphere. The derived emission limits for gaseous discharges are presented in Table 27.

Table 27: The limits for discharges to the atmosphere, Cernavoda NPP

Nuclide	Annular DEL (GBq)	Daily DEL (MBq)
Tritium	3,96E+06	1,08E+07
Carbon C-14	5,28E+03	1,45E+04
Noble gases	2,80E+06	7,86E+06
Iodine	3,28E+03	8,97E+03
Radioactive aerosols	3,23E+01	8,85E+01

CNCAN has established the limits for liquid discharges released into water. The derived emission limits for liquid discharges are presented in Table 28.

Table 28: The Limits for liquid discharges to water, Cernavoda NPP

Nuclide	Annular DEL (GBq)	Daily DEL (MBq)
Tritium	4,92E+07	1,35E+08
Carbon C-14	4,28E+01	1,17E+02
Iodine	3,24E+03	8,88E+03
Activation and fission products	4,04E+03	1,11E+04

10.3. Reporting obligations on discharge monitoring

CNCAN approves the Cernavoda NPP monitoring program for liquid and gaseous discharges. According to the regulatory requirements, the licensee must send CNCAN monthly and quarterly reports on all discharges.

The value of the gaseous and liquid discharge activity is a performance indicator of the Cernavoda NPP and is reported to the regulatory body (CNCAN) through quarterly technical reports (QTR).

The laboratories involved in the monitoring of discharges are reporting their results from the environmental radioactivity monitoring program and estimated public exposure doses, to CNCAN and the NPP management team.

The "Gaseous Effluent Weekly Summary" (containing H-3 and C-14 activities) and "Gaseous Effluent Weekly Summary for Isotopes with No DEL Calculated" (containing the total alpha and beta activities) are reported every week for each unit of the Cernavoda NPP.

All results of the environmental radioactivity monitoring program are included in an annual technical report, approved by CNCAN.

Gaseous and liquid discharges from nuclear power plant reactors are annually reported in accordance with Recommendation 2004/2/Euratom.

10.4. Compulsory technical requirements

CNCAN defines the detection limits for both liquid a gaseous discharges monitoring equipment in accordance with Recommendation 2004/2/Euratom, discussing standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation (notified under document n° C(2003) 4832).

Requirements for laboratories' analytical sensitivity are in terms of specific activity in gaseous effluents and have been calculated according to the NSR-21 "Norms on the monitoring of radioactive emissions from nuclear and radiological installations – Order no. 276/2005" as a DEL of 0.1 for an annual volume of gaseous discharges.

For tritium and radiocarbon C-14, the requirements are from Recommendation 2004/2/Euratom, because these are considered more restrictive.

The laboratories involved in monitoring of discharges must be designated by CNCAN as a "Testing Laboratory" in this topic. Laboratories are accredited as per regulation approved by the CNCAN president, under Order No. 237/ 2019.

According to the license conditions, the operator must participate in laboratory comparison exercises. All methods of analysis are verified by calibration and participation in international comparison exercises.

10.5. Main strengths and weaknesses of monitoring radioactive discharges

The effluents generated are well known (location of release, type of radionuclide, expected quantities, etc.), which allows Cernavoda NPP to adapt its monitoring strategy efficiently.

The detection equipment used is fit for the radionuclides being monitored. Online monitoring is equipped with redundant sampling lines and detectors in case of failure. To obtain a representative sample of the gaseous discharges, an isokinetic sampling nozzle with multiple inputs is installed in the ventilation stack. The system also includes a device for measuring the value of the average flow to the stack.

Cernavoda NPP has two authorised laboratories that perform measurements of discharge samples- the dosimetry laboratory located at the NPP site and the Environmental Control Laboratory (ECL) located outside of the plant. The laboratories are equipped with modern analysing systems to determine the natural and artificial radionuclide content in the discharge samples. The official results are used for reporting to the authorities.

The ECL is re-authorised every five years by CNCAN, according to Order no. 237/ 2019 and ISO/IEC 17025. The ECL maintains good results in comparison exercises/proficiency tests performed by international organizations such as the IAEA (Vienna), EC DG JRC, and the CANDU Owners Group.

The chemical/physical forms of tritium and carbon-14 that are monitored in the airborne effluent are:

- Elemental tritium (HT)
- Tritium oxide as water vapour (HTO)
- Radioiodine mixed fission products (Imfp)
- C-14 as $^{14}CO_2$ (^{14}C) (inorganic)
- C-14 as organically bound molecules

For iodine discharges to be conservative, it is assumed that I-131 is in equilibrium with the other iodine fission products with the following respective ratios: I-131/I-132/I-133/I-134/I-135 = 1.00/1.45/2.00/ 2.04/1.81.

Some of the measurements exceeded the detection limits in Recommendation 2004/2/Euratom. This issue was internally addressed, and actions to improve this occurrence will be implemented.

It should be mentioned that there is not a periodical discharge limit review to ensure the limits are still “fit for purpose” in Romania.

10.6. Compliance with Recommendation 2004/2/Euratom

Table 29 presents the results of a gap analysis completed for the key radionuclides in gaseous discharge that should be monitored according to Recommendation 2004/2/Euratom, and if they are reported in the EC RADD.

Table 29: Compliance with Recommendation 2004/2/Euratom for key radionuclides in gaseous discharge, Cernavoda NPP

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database	Highest value of the detection limit achieved at facility (Bq/m^3)	Detection limit in Recommendation (Bq/m^3)
Kr-85	N/A	N/A	1,00E+04
Xe-133	N/A	N/A	1,00E+04
Co-60	Yes	9,85E-02	1,00E-02
Sr-90	No	N/A	2,00E-02
S-35	N/A	N/A	1,00E+01
Cs-137	Yes	1,00E-01	3,00E-02
Pu-239+Pu-240	No	N/A	5,00E-03
Am-241	No	N/A	5,00E-03
I-131	Yes	1,42E-01	2,00E-02
H-3	Yes	3,81E+02	1,00E+03
C-14	Yes	3,40E+01	1,00E+01

The key radionuclides Kr-85, Xe-133 (which are not compulsory for Cernavoda reactor type (PHWR)) and Sr-90 were not reported in the year 2021, but are monitored on a daily and yearly basis.

According to CANDU Owner Group technical documents related to CANDU-specific source concentrations for Pu-239, Pu-240, and Am-241, the radionuclides are lower than one of the reference nuclides from the CANDU-specific mixture. To estimate the potential maximum specific activity for Sr-90 and Pu-239 + Pu-240, and Am-241, the scaling factors between these radionuclides and the concentration of Cs-137 in specific CANDU source term and the activity concentration of Cs-137 in radioactive gaseous effluents, have been used.

In the EC RADD, the value reported for Cs-137 was 0.0.

So far, Pu-239, Pu-241, and Sr-90 are not reported. However, the Nuclear operator states that in the future the values of these radionuclides will be reported.

As a result, the maximum potential specific activity for Sr-90, Pu-239, Pu-240, and Am-241 cannot reach or exceed the corresponding detection limits required by Recommendation 2004/2/Euratom. as much the maximum potential specific activity for Cs-137 is equal with Cs-137 detection limit (during the entire operation history of Cernavoda NPP there was no Cs-137 activity detected above detection limit).

Table 30 presents the result of a gap analysis for the key radionuclides in liquid discharge that should be monitored according to Recommendation 2004/2/Euratom, and if they are reported in the EC RADD.

Table 30: Compliance with Recommendation 2004/2/Euratom for key radionuclides in liquid discharge, Cernavoda NPP

Key radionuclides to be monitored as in the Recommendation	Is the radionuclide monitoring reported in RADD database?	Highest value of the detection limit achieved at facility (Bq/m^3)	Detection limit in Recommendation (Bq/m^3)
H-3	Yes	1,56E+05	1,00E+05
S-35	N/A	N/A	3,00E+04
Co-60	Yes	5,67E+03	1,00E+04
Sr-90	No	1,00E+03	1,00E+03
Cs-137	Yes	5,71E+03	1,00E+04
Pu-239+Pu-240	No	N/A	6,00E+03
Am-241	No	N/A	5,00E+01

The key radionuclide Sr-90 was never reported in Romania's EC RADD, the Sr-90 analysis is performed on the monthly composite sample. If the sum of the monthly gross beta measurement is higher than 20% of the yearly DEL (YDEL) for the most restrictive radionuclide of liquid releases (Cs-134 YDEL=1.99 GBq), then it must be reported.

The Cernavoda NPP does not report chemical/physical forms of tritium, carbon-14, and iodine discharges (Article 8(d) of Recommendation 2004/2/Euratom mentions to report "as fa as available")

Also, it should be mentioned that some measurements exceed the detection limits set in the Recommendation 2004/2/Euratom.

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