Risks of reactor Lifetime extension Doel-4 and Tihange-3

Opinion within the scope of the EIA procedure

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Table of contents

List of figures and tables

Summary

Introduction and Procedure

An environmental impact assessment is currently underway for extending the life of the two reactors Doel-4 and Tihange-3. In 2025 both reactors should be shut down after 40 years of operation, now they should be in operation for 10 years longer. However, these 10 years are only calculated from the first industrial power generation after 2025; the planned latest switch-off date is 12/31/2037.

The Doel-4 and Tihange-3 reactors were put into operation before the EIA legislation came into force. The life extension EIAs are thus the first EIAs to be carried out for these two reactors. Therefore, the changes in the environment since commissioning, such as the sharp increase in population density, should also be taken into account.

Since a serious accident in Doel-4 or Tihange-3 could affect large parts of Europe, it would be appropriate to hold a Europe-wide public hearing as part of the EIA.

Alternatives

Although the EIA report explains that any combination of energy forms that can ensure sufficient capacity and a high degree of operational reliability could theoretically be considered as an alternative, alternatives were not examined, but a political decision was made to extend the service life. The justification for extending the service life of Doel-4 and Tihange-3 is factually incorrect, because illogical conclusions are drawn from the current situation [1].

The political goal pursued with the lifetime extension, namely guaranteeing the security of the power supply, is also not secured, since the old reactors are also threatened by downtimes due to security-related events, just like in France.

In the period when there could be bottlenecks in the energy supply (2025 to 2027), the nuclear power plants would be switched off. They would only be connected to the grid again when additional offshore capacities are already connected or almost connected to the grid.

In addition, according to Elia, an increase in flexible capacity is required, but Doel-4 and Tihange-3 cannot meet this. However, an extension of the service life of Doel-4 and Tihange-3 would hinder the desired expansion of renewable energies.

A technically well-founded review of the possible alternatives through renewable energies must be carried out and their potential environmental impact evaluated comparatively instead of presenting a political decision based on illogical conclusions to extend the life of the reactors Doel-4 and Tihange-3 as without alternative and negating their environmental impact.

Nuclear waste

It is fundamentally problematic to approve a lifetime extension without the safe disposal of the nuclear waste, including its final storage, being assured. After all, the lifetime extension would result in around 810 additional spent fuel elements, which corresponds to an increase of 7.8% compared to the amount without lifetime extension. For these additional fuel elements, a more than 1.2 km long tunnel is required in a future repository. So this is not a negligible amount. This makes the complicated search for and construction of a repository even more difficult.

The planning of a repository for high-level waste in Belgium is also at a very early stage. It is by no means certain that operations will actually start in 2080 or that a repository will be found at all. The interim storage facilities and canisters should be checked to see whether they offer sufficient safety for the long period up to 2080 or, if necessary, beyond.

Weaknesses of the reactor type in long-term operation

The quality of the materials used in Doel-4 and Tihange-3 degrades through physical aging, which can lead to component failure. A precautionary replacement of components as part of aging management

[1] to rely on its own old nuclear power plants threatened with failure because of the failures of the French nuclear power plants; to become dependent on uranium to achieve fuel independence

can reduce the risks. However, the scope of the exchange is determined in consultation between the operator and the supervisory authorities and is dominated by economic considerations. Experience also shows that unexpected damage can occur over longer periods of operation. In addition, not all components can be replaced, for example the reactor pressure vessel. Overall, the risks increase with the operating time due to aging effects.

The security concept of Doel-4 and Tihange-3 is also outdated compared to current security requirements and regulations. The EIA report claims that the systems largely meet the new requirements, which is not true in any way compared to international requirements. Overall , the EIA report makes it clear that the safety requirements for the lifetime extension are to be reduced, which automatically leads to an increase in risk.

Due to the retrofits carried out so far, Doel-4 and Tihange-3 do not reach the safety level of new plants, design deficits relate to the area of beyond design basis accidents. Instead of technical upgrades, only measures by the operating team have been introduced so far. **To prevent a massive radioactive release, the operating team would have to try to prevent a serious accident under adverse conditions and essentially with mobile devices.** Note: In Sweden, reactors of the same type have been retrofitted with an independent core cooling system.

The most important safety goal for new nuclear power plants is the exclusion of core meltdown accidents with early and high releases. So far, this safety requirement has not been met for Doel-4 and Tihange-3. This fundamental safety objective must be met by new nuclear power plants. In the case of existing plants, on the other hand, it is conceded that the implementation of the requirements may not be "reasonably feasible". It therefore remains the task of the supervisory authority to check to what extent the planned measures are sufficient to meet the requirements for the necessary protection of the population. **The population and politicians have a right to know what deficits Doel-4 and Tihange-3 have compared to the current security requirements. Furthermore, they should receive information about which upgrades would be technically possible but should not be carried out for economic reasons.**

Unlike in France, where the current safety targets are used as the standard for retrofitting to extend the life of the old reactors in the 900 MW class, no attempt is made in Belgium to meet these requirements as part of the planned life extension.

As recommended by WENRA, Doel-4 and Tihange-3 should be checked for the lifetime extension as part of the PSR to determine the extent to which they meet the applicable safety targets for new reactors. Only on this basis can the supervisory authority decide whether continued operation for Doel-4 and Tihange-3 can be approved or whether the risk to the population is too great.

Dangers from natural events

Possible effects of natural hazards must be checked as part of the periodic safety reviews that take place every 10 years. If necessary, the results of the review should lead to an adjustment of the design basis of the plant and be included in the assessment of beyond design basis accidents. However, it is not clear from the EIA documents whether this process is to be carried out as part of the life extension for Doel-4 and Tihange-3. On the contrary, the wording suggests that a reassessment will not be carried out.

With regard to extreme impacts, the negative changes caused by climate change are mentioned, but at the same time the reassessment after the 2011 stress test is considered sufficient for the period up to 2037. If the flood protection system in Tihange fails, the area will be flooded, the safety systems will fail and the operating team will have to use mobile equipment from boats to prevent a core meltdown accident. A dyke breach can also lead to a dangerous situation.

In view of the existing and increasing danger from extreme natural events, the risks must be reassessed, which also takes climate change into account appropriately, instead of relying on the supposed existing safety reserves.

Dangers from terrorist and military actions

Terrorist attacks and acts of sabotage can have a significant impact on nuclear facilities and cause serious accidents - including for Doel-4 and Tihange-3. This applies in particular to the threat situation in Belgium presented. Yet they are hardly mentioned in the EIA document. Such events have been discussed to some extent in comparable EIA documents.

Although the Doel-4 and Tihange-3 plants are better protected than even older plants, their level of protection shows deficits compared to the level of protection expected today. In addition, the requirements in Belgium for such protection do not meet the currently required requirements.

The special threat situation in Belgium and the insufficient protection of the Doel-4 and Tihange-3 plants against terrorist attacks and acts of sabotage should play a decisive role in an assessment of the risk for the population by extending the operating hours.

Impact of a serious accident on Belgium and neighboring countries

The accidents calculated in the EIA documents (design basis accidents and beyond design basis accidents) can lead to intervention measures such as staying indoors or the administration of potassium iodide tablets having to be ordered in Belgium. Furthermore, both the design basis and the beyond design basis accident can lead to agricultural measures having to start.

However, it must be taken into account that these calculated accidents are by no means the worst possible accidents. A possible accident was calculated for both reactors in the flexRISK project. These results show that large parts of Europe could become contaminated. Areas northeast of the relevant nuclear power plants have the highest weather-related probability of being contaminated by a severe accident. Such an accident could even result in areas in and around Belgium having to be resettled.

The transboundary impacts for a major accident should be calculated in the EIA process, regardless of the estimated probability of occurrence, as long as it is physically possible in order to clarify the risk. The results of the flexRisk project determined the massive impact of such an accident for Belgium and Europe.

1 Introduction and Procedure

An environmental impact assessment is currently underway for extending the life of the two reactors Doel-4 and Tihange-3. In 2025 both reactors should be shut down after 40 years of operation, now they should be in operation for 10 years longer. However, these 10 years are only calculated from the first industrial power generation after 2025; the planned latest switch-off date is 12/31/2037.

This opinion is based on the following EIA documents:

- SCK CEN, Kenter, Sertius (2023a): Environmental Impact Assessment. In connection with the postponement of the shutdown of the Doel-4 and Tihange-3 nuclear assets. Release date: 03/20/2023. Cited as (SCK CEN 2023a)
- SCK CEN, Kenter, Sertius (2023b): Non-Technical Summary of the Environmental Impact Assessment. In connection with the postponement of the shutdown of the Doel-4 and Tihange-3 nuclear assets. Release date: 03/20/2023. Cited as (SCK CEN 2023b)

Both Doel and Tihange were put into operation before the EIA legislation came into force and have therefore not yet undergone an EIA in their original 40-year lifetime. This is now changing in the course of the term extensions. For many years it was disputed whether an extension of the term required an EIA at all. This has been clarified, among other things, by the successful lawsuit filed by Belgian NGOs regarding the lack of an EIA when the reactors Doel 1&2 were extended. Furthermore, since December 2020, the "Espoo Guidance on the Applicability of the Convention to the Lifetime Extension of NPP" (UNECE 2020) has regulated that term extensions require an EIA, also across borders.

In the analysis of the environmental impact, the situation of the shutdown of Doel-4 and Tihange-3 in 2025 was set as the "reference situation" and compared with the expected situation of the lifetime extension until 2037. However, what was not considered was a comparison with the situation in the mid-1980s when Doel-4 and Tihange-3 became operational. Apart from changes in various safety-related aspects, it must also be taken into account that the environment around the nuclear power plants has changed significantly in terms of population data in recent decades.

The Antwerp conurbation, which is now home to well over a million people, is around 30 kilometers from the Doel site. The population density was even lower when Doel-4 went live, and it was even lower when Doel-1&2 went live.

Table 1: Population in millions. The Doel site is located between the two provinces of Antwerp and East Flanders. Source: written communication EC/BBLV

Year	Province of Antwerp	Province of East Flanders
1970	1,538	1,310
1981	1,570	1,331
1990	1,597	1,332
2000	1,644	1,362
2010	1,745	1,432
2020	1,867	1,525

The EIA documents only deal with the immediate vicinity of the Doel nuclear power plant (5 km), whose population density is described as low in the EIA report (SCK CEN 2023a).

In the Espoo guidance on lifetime extension, reference is made to changes in the environment or the surroundings of the nuclear power plant, which should also be interpreted as "major change":

"2. "Lifetime extension per se"

49. It is unusual for lifetime extensions to be carried out without, inter alia, any associated physical works or modifications in the operating conditions. Nevertheless, irrespective of whether or not there are physical works or modifications in the operating conditions, the operation of a nuclear power plant *is faced with a changing environment that occurs over the course of its lifetime and that may not have been considered in the initial authorization to operate. With respect to the decision on the lifetime extension, the changed environment, depending on its nature and scale, could constitute a factor that may indicate that the change in the likely im pact of the proposed activity could, as such, be classified as a major change ." (UNECE 2020 III.C)*

Such an interpretation means that the changes in the population density in the vicinity of the nuclear power plant can be seen as a "major change", and this aspect should therefore also be taken into account in the environmental assessment.

Even if it is fundamentally a step forward that environmental impacts have to be assessed for service life extensions, the question remains to be clarified for each individual EIA procedure as to whether sufficient information is made available early enough to really assess the environmental impacts in the necessary level of detail and quality to be able to judge.

One of the contentious points of any EIA for a new nuclear power plant or life extension is whether the consequences of the worst possible accident were actually used to describe the potential impact of the project. (see chapter 7)

Furthermore, an EIA must contain all the information that allows the condition of the system to be checked. This includes all work that was or will be carried out in the course of the extension of the term. However, it is already becoming apparent that the necessary safety-related work on the reactors would take years [2]. It is also stated that they will not be completed before the start of the term extension.

Since a serious accident at Doel-4 or Tihange-3 could affect large parts of Europe, it would be appropriate to hold a Europe-wide public hearing as part of the EIA process.

1.1 Conclusions and Demand

The Doel-4 and Tihange-3 reactors were put into operation before the EIA legislation came into force. The life extension EIAs are thus the first EIAs to be carried out for these two reactors. Therefore, the changes in the environment since commissioning, such as the sharp increase in population density, should also be taken into account.

Since a serious accident in Doel-4 or Tihange-3 could affect large parts of Europe, it would be appropriate to hold a Europe-wide public hearing as part of the EIA.

2 alternatives

The EIA report explains that the 10-year life extension of Doel-4 and Tihange-3 is primarily a political decision , driven by unexpected developments in the energy market and geopolitical situation in Europe. The political aim pursued in this way is to *guarantee the power supply* . Theoretically, any combination of energy forms that can guarantee sufficient capacity and a high degree of operational reliability could be considered as an alternative. (SCK CEN 2023a)

The capacity remuneration mechanism (CRM) was previously seen as the preferred solution for bridging the period between the planned final shutdown of all nuclear power plants in 2025 and the point at which sufficient renewable energy capacity would be available. Although the **CRM mechanism is** in principle open to any type of capacity, in practice, according to the EIA report, it appears that gas-fired power plants (CCPP) are mainly used. (SCK CEN 2023a)

Elia calculated in 2021 that in 2025, there would be a need for additional generation capacity of around 3.6 GW. The capacity built up in this way must be able to be used flexibly. According to Elia, the additional capacity available in 2025 is around 4.48 GW. The EIA report explains that this capacity is in

[2] https://fank.fgov.be/de/dossiers/kernkraftwerke-belgien/langzeitbetrieb-lto-von-doel-4-und-tihange-3-bis-2035 , viewed 09.05.2023

principle sufficient to fill the capacity gap that will emerge from 2025 onwards, but the government does not want to rely solely on CRM capacity. According to the EIA report, this is therefore not a real alternative, but an additional guarantee which, in combination with the runtime extension of Doel-4 and Tihange-3, ensures the security of the electricity supply. (SCK CEN 2023a)

A surge in renewable energy is also helping to offset some of the deficit, according to the EIA report. **In fact, the expansion of renewable energies in Belgium is in full swing.** At the end of 2021, the total installed renewable energy capacity in Belgium was 13.06 GW and the share of total Belgian generation was around 18%. In 2022, the share of renewable energies in total Belgian electricity generation was already around 23.1 percent. The renewable energies consist of biomass, solar and wind energy (onshore and offshore).[3] **Nevertheless, the EIA report explains that the capacity of renewable energies is not yet sufficiently developed and is therefore not an alternative to lifespan extension. This statement is an assertion that is not correct on the one hand and, on the other hand, the expansion could be further accelerated through measures.** It should be noted that in recent years in the EU there has been a strong growth in electricity generation from renewable energies.[4] **On this basis, a reassessment of the possible alternative of renewable energies to close the capacity gap should be carried out** .

Part of the strategy to phase out nuclear power plants was the build-up of offshore wind capacity. In mid-2021, Belgium reached an installed capacity of 2.3 GW. Offshore wind development is set to continue with the designation of a second zone in the North Sea, where the first turbines will come online in 2027-2028, eventually adding 3.1-3.5 GW to the national fleet. (WNISR 2022)

According to the EIA report, the energy crisis and the war in Ukraine have changed the framework. In addition, there were the problems with the French nuclear power plants, because at times more than half of the French nuclear power plants were not in operation. It would therefore be obvious that the gaps that may arise as a result of the phase-out of nuclear energy should be closed as far as possible with our own capacities.

The EIA report explains that the government wants to focus more on domestic production capacity and reduce dependence on (foreign) fossil fuels. In this context, extending the service lives of Doel-4 and Tihange-3 is a logical decision. (SCK CEN 2023a) The government justifies its decision with the war in Ukraine. But what the war in Ukraine shows above all is that nuclear facilities are extremely dangerous in wartime situations. The intention to become less dependent on fossil energy sources and instead dependent on uranium imports is not logical. Inaccurate conclusions are also drawn from the massive failures of nuclear power plants in France. **The fact is that aging nuclear power plants cannot guarantee security of supply, so it can be assumed that extending the service life of the Belgian nuclear power plants does not guarantee security of supply either. In addition to the age-related failures, supply failures due to climate-related shutdowns and throttling of the systems are to be expected.**

The EIA report goes on to state that the extension of Doel-4 and Tihange-3 operations is of particular importance for the period up to around 2028; after that, an additional capacity of around 2.2 GW of wind power from the newly developed Princess Elisabeth Zone in the North Sea should become available. According to the EIA report, Doel-4 and Tihange-3 are scheduled to start up again in autumn 2027 after being shut down in 2025. (SCK CEN 2023a) **The planned off-shore plants would then almost be available as an alternative. In this respect, there is no need to extend the term until 2037** . In addition, they would only make a relative capacity of 2 GW available again to the grid.

An assessment of the environmental impact was made for the period of continued operation in comparison with the scenario if the shutdown had not been postponed (this is seen as the reference state). (SCK CEN 2023a) **In the analysis of the environmental impacts of extending the operation of Doel-4 and Tihange-3, no comparison is made with the impacts of alternative solutions, as it is (incorrectly) claimed that there is no alternative.** It is explained at the outset that the life extension plan is a political

[3] https://de.statista.com/statistics/data/study/182166/umfrage/struktur-der-grossstromENERATION-in-belgien/

[4] In 2020, they replaced fossil fuels as the most important energy source for the first time.

decision. This is also made clear by the fact that a serious and factually logical examination and evaluation of the existing alternatives is not carried out.

It is also a fact that nuclear power plants do not – as Elia says – provide the required flexible capacity and the operation of nuclear power plants also hinders the expansion of renewable energies.

SOVACOOL et al. (2020) analyzed renewable and nuclear power generation in 123 countries over a 25-year period. They found that larger national nuclear energy shares are not usually significantly associated with lower CO_2 emissions, but that renewable energies are. They also found a negative association between the level of national attachment to nuclear power and growth in renewable energy. This indicates that nuclear energy and renewable energies are crowding out each other.

It is now known that the base load concept of nuclear power plants is not necessary for a transition to a 100% renewable energy supply and is even counterproductive. The limited flexibility of nuclear power plants and their technical [5]and economic problems with load-following operation have become a handicap that impedes cost-effective and stable grid operation with an increasing share of carbon-free, low-cost variable renewable energy. (WNISR 2019)

In a recently published study, the "Scientist for Future" emphasize that nuclear energy blocks the socio-ecological transformation to a climate-friendly energy supply. (WEALER et al. 2021) The ultimate challenge of the great transformation, i.e. the initiation of the socio-ecological reforms that will lead to a viable and climate-neutral energy system, lies in overcoming the resistance ("lock-in") of the old, from system dominated by the interests of fossil fuels. However, nuclear energy is not suitable to support this process. On the contrary, she blocks him. The investments required for dead-end technology are crowding out development in renewable energy, energy storage and efficiency. Given the competitive environment, nuclear power producers have an incentive to prevent or minimize investment in renewable energy.

In an article published earlier this year, Jean-Jacques Nieuviaert (President of the Société d'Etudes et de Prospective Energétique (SEPE)) pointed out [6]that increased load following operation means higher costs and lost revenue for EDF in France. As a solution, he suggested, among other things, a throttling of the expansion of renewable energies. (NIEUVIAERT 2023)

The conclusion of a study recently published in Germany on the discussed lifetime extension of German nuclear power plants was that an additional inflexible feed-in of several GW, as would be the case with nuclear power plants, would have massive negative effects on the German electricity market for the expansion of renewable energies and the economy. (BEE 2023)

2.1 Conclusions and Demand

Although the EIA report explains that any combination of energy forms that can ensure sufficient capacity and a high degree of operational reliability could theoretically be considered as an alternative, alternatives were not examined, but a political decision was made to extend the service life. The justification for extending the service life of Doel-4 and Tihange-3 is factually incorrect, because illogical conclusions are drawn from the current situation [7].

[5]The flexible operation, the so-called load-following operation, is technically problematic for nuclear power plants. Load-following has an impact on the installations, leading to an increase in random events (on average + 25%) and aging of the primary circuit. Load following means that the reactors are subjected to more mechanical stress, which leads to faster wear of certain parts.

[6]Society for energetic studies and future research

[7]to rely on its own old nuclear power plants threatened with failure because of the failures of the French nuclear power plants; to become dependent on uranium to achieve fuel independence

The political goal pursued with the lifetime extension, namely guaranteeing the security of the power supply, is also not secured, since the old reactors are also threatened by downtimes due to security-related events, just like in France.

In the period when there could be bottlenecks in the energy supply (2025 to 2027), the nuclear power plants would be switched off. They would only be connected to the grid again when additional offshore capacities are already connected or almost connected to the grid.

In addition, according to Elia, an increase in flexible capacity is required, but Doel-4 and Tihange-3 cannot meet this. However, an extension of the service life of Doel-4 and Tihange-3 would hinder the desired expansion of renewable energies.

A technically well-founded review of the possible alternatives through renewable energies, efficiency, demand management and other flexibility measures must be carried out and their potential environmental impact evaluated comparatively instead of presenting a political decision based on illogical conclusions to extend the life of the reactors Doel-4 and Tihange-3 as without alternative and negating their environmental impact.

3 nuclear waste

Spent fuel elements and radioactive waste can cause negative consequences for people and the environment. Proof of safe disposal is required to prevent this. This proof initially includes an estimate of the additional inventory of spent fuel assemblies and radioactive waste expected from the lifetime extension, with the spent fuel assemblies representing the greatest risk.

According to the EIA report (SCK CEN 2023a), the 10-year life extension will also result in the following spent fuel assemblies:

- Doel-4: Approximately 390 spent fuel assemblies will be generated (3.5% of the total Belgian stock), which will be stored dry in the on-site interim storage facility (SCG) after a cooling-off phase in the storage pool. The capacity of the SCG is expected to be exhausted in 2024. A new interim storage facility, the SF [2], is to be in operation by 2025 . **The space requirement for the additional spent fuel elements would correspond to a tunnel length of approx. 600 m in a future repository.**
- Tihange-3: Approximately 420 additional spent fuel assemblies will be generated (3.8% of the total Belgian inventory). After the cooling phase in the storage pool, the spent fuel elements are currently stored in a wet storage facility at the site (DE), the capacity of which was already exhausted in 2022. An SF [2] interim storage facility for dry storage is currently under construction and is scheduled to go into operation in 2023. **The space requirement for the additional spent fuel elements would correspond to a tunnel length of approx. 650 m in a future repository.**

For proof of disposal, it is decisive whether the required disposal facilities are available in the required capacity in good time. There are currently not enough interim storage capacities available for the additional spent fuel assemblies resulting from the lifetime extension, but these are already under construction. The two SF [2] interim storage facilities are designed for a service life of 80 years. (JOINT CONVENTION 2020)

The situation is different with the final storage capacities. A royal decree of November 22, 2022 lays down the fundamental decision on deep geological disposal on Belgian sovereign territory. The responsible nuclear waste authority NIRAS is currently preparing a methodological safety and feasibility file for the geological disposal, which is planned for 2025. In the course of the extension of the service life for Doel-1 & 2, the Belgian side informed that a repository for high-level waste could go into operation at the earliest in 2080 (UMWELTBUNDESAMT 2021). This means that the interim storage in the existing interim storage facilities must be carried out for more than 80 years, or even longer if the schedule for the repository is delayed. In any case, it must be proven in good time whether the interim storage facility and the casks are designed for long-term interim storage.

3. 1 Conclusions and claim

It is fundamentally problematic to approve a lifetime extension without the safe disposal of the nuclear waste, including its final storage, being assured. After all, the lifetime extension would result in around 810 additional spent fuel elements, which corresponds to an increase of 7.3% compared to the amount without lifetime extension. For these additional fuel elements, a more than 1.2 km long tunnel is required in a future repository. So this is not a negligible amount. **This makes the complicated search for and construction of a repository even more difficult** .

The planning of a repository for high-level waste in Belgium is also at a very early stage. It is by no means certain that operations will actually start in 2080 or that a repository will be found at all. The interim storage facilities and the canisters should be checked to see whether they offer sufficient safety for the long period up to 2080 or even beyond.

4 weaknesses of the reactor type in long-term operation

The Tihange NPP is located on the right bank of the Meuse and is operated by Engie-Electrabel. The plant consists of three pressurized water reactors. The final shutdown of Tihange-1 is scheduled for 2025. Tihange-2 was finally shut down in February 2023. Tihange-3 was first connected to the grid in 1985 and was scheduled to be finally shut down in 2025 after 40 years of operation. An extension of the service life up to a maximum of 2037 is now planned.

The Doel nuclear power plant is also operated by Engie-Electrabel and is located in the port of Antwerp on the left bank of the Scheldt. It is the nuclear power plant in Europe that is located in the most densely populated area: around nine million people live within a radius of 75 kilometers. The Doel nuclear power plant comprises four pressurized water reactors. The final shutdown of reactors Doel 1&2 is scheduled for 2025. Doel-3 was finally shut down in September 2022. Doel-4 was also connected to the network for the first time in 1985 and is to be extended to a maximum of 2037.

Doel-4 and Tihange-3 are Westinghouse 3-Loop (WH 3LP) pressurized water reactors with a net capacity of 1038 MW. In Europe, two WH 3LP reactors (Ringhals [8]3 and 4), which were first connected to the grid in 1980 and 1982 respectively, [9]are still in operation in Sweden , and five WH 3L reactors (Almaraz 1-2, Asco 1-2, Vandellos 2) operated. These reactors were connected to the grid between 1981 and 1987.

The containment of Doel-4 and Tihange-3 is designed as a double containment with an inner metal liner. Doel-4 and Tihange-3 have a fuel pool for storing spent fuel outside the containment. The fuel element storage pool is located in a separate storage pool building adjacent to the reactor building. The degree of protection of the structure of this building against external impacts is significantly lower than that of the containment.

Aging management for life extension

The EIA report explains that, as part of the aging management, it must be proven for all safety-relevant systems, buildings and components that their qualifications remain valid in the new operating period. This can be done either through appropriate analysis or by replacing these components before they exceed their qualified service life. For the large mechanical components (reactor vessel, reactor head, steam generator) FANC estimates based on current knowledge that they do not need to be replaced. (SCK CEN 2023a) Large components have already been replaced: the steam generators in 1997 (Doel-

[8]The Doel 3 and Tihange 2 reactors, which have already been shut down for good, are also WH 3LP reactors.
[9]Ringhals 2, also a WH 3L reactor, was finally shut down in December 2019.

4) and 1998 (Tihange-3) and in 2015 the covers of the reactor pressure vessels of both blocks. (FANC 2019a)

For other components (smaller mechanical components such as pumps or valves, electrical equipment, instrumentation, structures) there is currently no full picture of possible replacement work before the operator has completed its studies. [10]According to the EIA report, the actual list of works to be carried out as part of LTO Doel-4 and Tihange-3 is subject to change in consultation between the operator, Electrabel SA, and the safety authorities. (SCK CEN 2023a)

As in every industrial plant, the quality of the materials used in a nuclear power plant also decreases during operation, particularly as a result of physical ageing. [11]Irradiation by ionizing radiation, thermal and mechanical stress as well as corrosive, abrasive and erosive processes cause the components to age. The consequences of the aging processes include the occurrence of embrittlement, crack formation and growth or changes in electrical and other physical properties. The damage mechanisms associated with these phenomena are largely known as individual effects - but their actual long-term effects and, above all, their interaction in stress collectives are often not. **It is also to be expected that over a longer period of use, additional, previously unknown damage mechanisms will occur.**

The original operating permits were expected to run for 40 years. For this period, the number of load changes and the neutron flux were used to calculate the safety reserves: i.e. the number of load changes of pressure and temperature and the amount of neutron radiation that the materials under stress have to withstand. The safety reserves of the plant have decreased with age. (INRAG 2021)

reactor pressure vessel

The component of a reactor that cannot be replaced is the reactor pressure vessel. The neutron radiation that emanates from the reactor core inside during operation means that the material of the RPV wall becomes increasingly brittle over the period of operation. During an accident with a loss of reactor cooling and emergency cooling water being fed in , the RPV could fail if the material was embrittled. This would result in core damage and a massive release of radioactive materials. As a prerequisite for the approval of the lifetime extension, it must therefore be demonstrated that the integrity of the RPV is ensured until the end of the desired lifetime. (INRAG 2021)

The degree of RPV embrittlement in Doel-4 is not addressed in the EIA report . According to FANC (2017a), the RPV in Doel-4 was subjected to ultrasonic investigations in September/October 2015 and the RPV in Tihange-3. No crack indications (due to hydrogen flakes) were detected. In 2012, thousands of crack indications in Doel 3 were also found in Tihange 2 in the core rings. Doel 3 and Tihange 2 were finally shut down in September 2022 and February 2023 respectively. On these dates, the plants reach their design age of 40 years.

Damage to security-relevant buildings

In October 2017, Electrabel identified serious defects in the concrete of the building adjacent to the Doel-3 reactor buildings and containing the 2nd level safety systems. Similar problems were found at Tihange-3 and Doel-4: In 2018, concrete damage caused by heat and humidity was found at Tihange-3, and "anomalies" were found in the positioning of the steel reinforcements in the concrete. According to Engie, some of these anomalies in the reinforced concrete reinforcements have been present since the building was constructed. The incident was classified as level 1 on the INES scale. Such concrete damage was also discovered in Doel-4 in 2018, which also resulted in an INES 1 classification (FANC

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[10]In addition to design improvements and aging management, the Nuclear Safety Authority has also identified human resources (HR) as a factor that should not be underestimated for long-term operations. However, this is outside the scope of environmental impact assessment.

[11]Physical aging is the process by which the physical properties of structures, systems or components (SSC) change over time or through use.

2020b). These bunkered buildings contain plant safety systems and are designed to withstand an external impact such as a plane crash.

Doel-4 and Tihange-3 obsolescence and retrofits

In addition to the physical aging of structures, systems and components (SSCs), the safety of a nuclear power plant can also be affected by the obsolescence of technology, concepts and personnel skills.

Conceptual aging is primarily reflected in an outdated security concept compared to current security requirements and regulations. In general, the design must ensure that incidents and accidents are controlled or prevented. Serious accidents such as Three Mile Island, Chernobyl and Fukushima have shown that there are fundamental safety problems, especially in old nuclear power plants. **Not all design deficits can be eliminated by retrofitting: A significant part of the safety standards are already defined when the nuclear power plant is designed and can fundamentally no longer be improved by retrofitting.**

Retrofitting of additional security systems is only possible to a limited extent due to the structural conditions. Compliance with today's safety standards would practically require a completely new construction of a nuclear power plant. The differences that cannot be remedied relate in particular to the protection against external influences and insufficient precautions against beyond-design-basis accidents.

The retrofitting also does not reach the safety level of new systems because - instead to carry out technical upgrades in the field of precaution - often only emergency measures are put in place. (INRAG 2021)

The IAEA offers its member states so-called SALTO missions (*Safety Aspects of Long Term Operation*), in the context of which an international team of experts assesses the measures and processes for extending the service life on the basis of the IAEA standards. Belgium has not claimed a similar mission for Doel-4 and Tihange-3. (IAEA 2023)

Security requirements for the term extensions

According to the EIA report, Doel-4 and Tihange-3 currently comply with the current safety regulations set out in the Royal Decree of 30 November 2011. These regulations were tightened in 2020 and from 2025 additional safety requirements will apply. These must be applied as part of the next security review.[12] **The changes that result from this can only be evaluated after a comprehensive review.**

Nevertheless, the EIA report explains that the plants largely comply with the new requirements. As Doel-4 and Tihange-3 are among the most modern reactors in Belgium and have already been the subject of several improvement projects (through the three previous periodic safety reviews and the post-Fukushima stress tests), the potential needs identified according to the EIA report are not particularly complex. According to the EIA report, a distinction will be made between the "necessary requirements" for full compliance with the more stringent requirements that must be implemented before the start of the extension of operations after 2025, and the "possible adjustments" that can possibly be implemented afterwards without compromising safety to affect. (SCK CEN 2023a)

The key design improvements identified as "necessary requirements" are as follows:

- Dealing with potential heat waves can lead to design improvements, e.g. B. to additional air coolers or humidifiers in rooms;

[12] In 2014, WENRA increased its requirements based on the lessons learned from Fukushima. The new aspects of the 2014 WENRA reference levels have been included in the 2020 Belgian regulation. (FANC 2020c) These new requirements had not yet been used in the 3rd PSR in 2015 and would have to be applied in the context of the new PSR in 2025.

- Strengthening of the emergency planning centers: Structural improvements such as better shielding or ventilation of the emergency planning centers;
- The existing cooling systems of the storage pools could be improved and supplemented by additional (mobile) cooling systems that can be switched on in accident situations.

The EIA report lists a number of measures that result from required improvements as part of the periodic safety reviews and the EU stress test. **However, some of the previous upgrades have only been to restore the safety condition that was pre-permitted and has deteriorated with aging** (such as the renovation of concrete damage to the buildings).

In addition, reference is made to some measures to improve fire protection (e.g. installation of additional fire alarm systems). An example of the fact that despite extensive retrofitting in old nuclear power plants, current safety standards are not met is the fire protection implemented in old plants. Fire protection in old systems relies on active measures, which can fail, instead of appropriate spatial separation (passive measures). (INRAG 2021)

The safety requirements at the time of the design and construction of Doel-4 and Tihange-3 were significantly lower than at present.

The IAEA has created a set of rules that specifies the safety requirements for nuclear power plants according to the state of the art in science and technology. The basic objective for the safety of nuclear power plants is that:

- (Early) releases of radioactive materials due to early failure or by-passing of the containment, which require off-site emergency response measures, but for which there is insufficient time to implement, or
- (Large) releases of radioactive substances that require spatially extensive and long-lasting off-site accident management measures

practically ruled out [13]or the radiological effects are to be limited to such an extent that off-site accident management measures are only required to a limited extent in terms of space and time. (IAEA 2016)

This fundamental safety objective must be met by new nuclear power plants. In the case of existing plants, on the other hand, it is conceded that the implementation of the requirements may not be "reasonably feasible". It therefore remains the task of the national supervisory authorities to check to what extent the planned measures are sufficient to meet the requirements for the necessary protection of the population.[14]

According to European Directive 2014/87/EURATOM, the "reasonably practicable" safety improvements for the nuclear power plants in operation should be carried out. (EU 2014) This non-binding requirement is implemented differently by the supervisory authorities in the individual countries. Because what exactly is to be understood by this term is not specified. There are now new safety requirements for nuclear power plants in Europe. **But the supervisory authority and the operator continue to negotiate together and in camera about which upgrades are "reasonably feasible".** This means that they will not be carried out if they appear too expensive or technically too complicated. **The population should be involved and politicians should be involved in a decision to extend the operating time despite the existing and increasing dangers .**

The third periodic safety review (PSR) for the Doel-4 and Tihange-3 units took place in 2015. The fourth PSR will have to be carried out in 2025. **The Western European Nuclear Regulators Association (WENRA) recommends that when a plant is extended as part of the PSR, it should also be checked**

[13] The occurrence of an event or sequence of events or condition can be regarded as excluded if occurrence is physically impossible or if occurrence can be regarded as extremely improbable with a high degree of certainty.
[14] This also means that a risk would have to be accepted for old plants that new plants should not have.

to what extent it also meets the applicable safety targets for new reactors (WENRA 2011) [15], but this approach is not followed in Belgium. Such a test would make it clear which safety margins (deltas) exist to today's required safety standard.

The EIA report does not explain which safety objectives the assessment was based on. How safe a nuclear power plant is can only be assessed if the risks are known. Without a risk report that presents and evaluates open issues, assumptions, estimates of the remaining risk, it is not clear how far away the systems really are from the current safety goals. The requirements for the retrofits should be designed in such a way that they limit the risk of operating a plant to the socially acceptable level, based on the state of the art in science and technology. (INRAG 2021) **The population and politicians have a right to know what deficits Doel-4 and Tihange-3 have compared to the current security requirements. Furthermore, they should receive information about which upgrades would be technically possible but should not be carried out for economic reasons.**

The safety goals of the current Westinghouse reactor (AP1000), for example, could also be the benchmark or objective for extending the service life of Doel-4 and Tihange-3. The AP1000 with an output of 1000 MW is a pressurized water reactor of today's 3rd generation of nuclear power plants. The safety concept of the AP1000 is primarily based on passive safety systems. Westinghouse had been working on a new design since the 1990s. A comparison of the design of Doel-4 and Tihange-3 with the AP1000 would show what security improvements would be needed to meet current requirements.

In France, the safety targets for the EPR under construction at Flamanville 3 (EPR-FLA3) are used as the benchmark for the lifetime extension test of the old reactors of the 900 MW class [16]. The EPR is also assigned to the 3rd generation of nuclear reactors. Severe accidents were not taken into account in the design of the French 900 MWe reactors. The EDF therefore intends to improve the safety of the old reactors in the event of a core meltdown accident. EDF has planned upgrades as part of the 4th PSR of the 900 MWe reactors to limit the impact of core meltdown accidents. [17]The strategy envisaged by EDF to limit the risk of foundation meltdown is to solidify and cool the corium over the long term after reactor pressure vessel (RPV) failure. EDF also wants to install a system (EASu-System) to dissipate the residual heat from the containment without releasing it via the Filtered Venting System in the event of a serious accident . [18](EDF 2018a)

Beyond Design Accidents

The EIA report explains that an envelope beyond design basis accident was determined for Doel and Tihange based on a probabilistic safety analysis and in line with the 2014 WENRA Guidelines, which take into account the lessons learned from the 2011 TEPCO Fukushima accident. For this scenario, a " **complete station black-out" (CSBO) with core meltdown** (according to DEC-B) is assumed, provided that the emergency measures are successful. As a result of a core meltdown in this accident, the radioactivity is released to the environment both through a containment design leak and through controlled vents when pressure over the Containment Filtered Venting System (CFVS) rises too high. Multiple vents and a continuous design leak are assumed to exist over a 10-day period. The CSBO accident also includes events of external origin, including the crash of an airplane, according to the EIA report. (SCK CEN 2023a)

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[15] In a pilot study on extending the service life of nuclear power plants, the possible procedure for comparing the safety requirements of existing reactors with the current requirements as part of a periodic safety review (PSÜ) is illustrated.

[16]The extent to which the safety goals are achieved is not evaluated here.

[17] The EDF's work focused on dissipating the decay heat without opening the Filtered Venting System and stabilizing the molten core.

[18]Whether the systems can work reliably has not yet been proven.

A complete station black-out (CSBO) consists of a loss of the external power supply and the internal first and second level power supplies.[19] **The complete station blackout (CSBO) scenario was considered to be beyond design basis for which no design provision is made** . **The stress tests showed that there are only very short intervention times for the operating team for this event** : In a CSBO, only the turbopump of the auxiliary feed water system (AFW system [20]) is available for a short time to feed water into the steam generators (SG). A so-called cliff-edge effect [21]occurs when the AFW tank is exhausted, which is the case after eight hours in Doel-4 and after 23 hours in Tihange-3. There are limited ways to refill the AFW tank. (FANC 2011)

If the cooling via the steam generators fails, the primary circuit begins to boil and constantly loses water. This leads to exposure and later melting of the fuel, displacement of the corium to the bottom of the reactor pressure vessel (RPV) and puncturing of the bottom of the RPV. Without the intervention of the operating team, this process takes 2-3 hours. The time can be extended if non-conventional means such as fire water diesel pumps can be used to supply water. (FANC 2011)

A particularly dangerous situation occurs when the primary circuit e.g. is open for refueling. When the primary circuit is open, the water in the primary circuit will start to boil within 30 to 60 minutes. On-site manual actions are required to ensure water make-up in the primary system (which would take approximately 45 minutes) and to prevent a pressure build-up in the containment vessel which could result in the primary circuit gravity feed being blocked and the containment failure pressure reached. In Tihange-3, gravity feeding is not possible, and fuel meltdown would occur after 3 hours - if no measures were taken to refill the primary circuit. (ENSREG BE 2012)

Although the stress test showed that the deficiencies are large and the impact could be severe, the remedial action is limited. The basic problem that the operating crew has to use mobile equipment to quickly prevent a serious accident remains : In Doel-4, nozzles were installed at the inlet and outlet of the spray pumps in 2014 and 2015, as well as connections to the emergency cooling system and the emergency feed water system. In the case of a CSBO, mobile pumps are used to achieve an alternative water make-up for the reactor via this system. The mobile pumps and the mobile generators are stored in a newly built storage building. A new fire engine, which is multifunctional and can take on the role of a mobile pump in the event of a CSBO, is present. In Tihange-3, the CSBO strategy basically consists of using existing equipment (e.g. safety diesel) and using additional equipment (fixed and mobile). (FANC 2019b)

In Sweden, the deficits of this type of reactor were dealt with differently: An independent core cooling system (ICCS1**) was installed in units 3 and 4 of the Ringhals nuclear power plant in 2020** [22]. The purpose of the ICCS is to provide alternative core cooling when the normal safety systems are unavailable in the event of an event attributable to Extended Design Conditions (DEC). (CNS 2022)

The accident presented in the EIA report is intended to be representative of all beyond design basis accidents that are caused by external events. However, it is also assumed that the emergency measures are successful in order to prevent severe accident sequences. However, this cannot be seen as proven in all accident sequences such as simultaneous flooding of the site or the facility. After that, the water supply must be provided by measures of the plant-internal emergency protection. The heat dissipation must be dissipated with emergency measures of the operating team. **In addition, some accident sequences are possible with this type of reactor, which are not covered by this accident scenario.**

[19]Doel-4 and Tihange-3 have two levels of safety systems: the first level is designed for accidents of internal origin (e.g. Loss of Coolant Accident (LOCA)), the second level for external hazards.
[20]Auxiliary Feedwater
[21]a point where a situation changes very suddenly and completely for the worse, or where something suddenly deteriorates significantly, like stepping off a cliff
[22]Independent core cooling system

Filtered containment venting has been considered state of the art for several decades. In 2011, none of the Belgian nuclear power plants were equipped with it. Filtered containment vent systems were installed in Doel-4 and Tihange-3 and became operational at the end of 2017. (FANC 2019b) **Filtered containment venting systems reduce the risk of large releases during a meltdown accident, but not for all accident sequences** (see below).

With regard to beyond-design-basis accidents (4th safety level), there is a significant deficit in the thickness of the foundation for Tihange-3, which at 2.64 m (FANC 2011) is significantly less than in new plants.[23] **In the event of a core meltdown accident, the integrity of the safety enclosure (containment) cannot be adequately guaranteed, which would result in a significant radioactive release.** Effective retrofitting is not possible here. A core catcher, such as B. in the EPR or other reactors of the 3rd generation, can no longer be implemented later. As a result of a core meltdown accident

Radioactive releases (source term)

The EIA process examined the effects of two design basis accidents, the Loss Of Coolant Accident (LOCA) and the Fuel Handling Accident (FHA) and one beyond design basis accident involving a Complete Station Blackout (CSBO). meltdown, which is considered representative of this type of accident. Although they are very similar reactors, there are differences in the release of radioactivity into the environment between Doel-4 and Tihange-3. These are related to differences in the design of the reactors. (SCK CEN 2023a) The following table lists the source terms.

Table 2: Radioactive releases (source terms) for the accidents calculated in the EIA report (SCK CEN 2023a)

Doel-4 / Tihange-3	*design basis accidents*		*Beyond design basis accident*
	LOCA	*FHA*	*CSBO*
iodine	64.5TBq /11.9TBq	7.23TBq/ 10.1TBq	0.49TBq / 0.25TBq
Cs-137 (+Cs-134)[24]	1.88GBq / 11GBq	-	58.3GBq /0.38TBq

The source terms used in the FlexRisk project were taken from published studies on potential releases from probabilistic safety analyses.

An Interfacing Systems Loss-Of-Coolant Accident (ISLOCA) is a breach in a system that interfaces with the Reactor Coolant System (RCS) that can result in a Loss-of-Coolant Accident if the breach is not isolated from the RCS. [25]Having parts of a port system outside the containment vessel can result in a release of radionuclides that bypasses the Filtered Venting System. **In such an accident scenario, 30% of the iodine and cesium inventory of the respective reactor core would be released** . (FLEXRISK 2012)

4.1 Conclusions and Demand

The quality of the materials used in Doel-4 and Tihange-3 degrades through physical aging, which can lead to component failure. A precautionary replacement of components as part of aging management can reduce the risks. However, the scope of the exchange is determined in consultation between the operator and the supervisory authorities and is dominated by economic considerations. Experience also shows that unexpected damage can occur over longer periods of operation. In addition, not all components can be replaced, for example the reactor pressure vessel. Overall, the risks increase with the operating time due to aging effects.

The security concept of Doel-4 and Tihange-3 is also outdated compared to current security requirements and regulations. The EIA report claims that the systems largely meet the new requirements, which is not true in any way compared to international requirements. Overall , the EIA report makes it clear that the

[23] The foundation of Doel-4 has a thickness of 3.45 m (FANC 2011) , which may be sufficient to prevent the foundation from melting through **.**

[24]C-134 is only included in the beyond design basis accident.

[25] Such a rupture can be caused when valves that isolate the RCS from a port system that is not designed to withstand the high RCS pressures fail

safety requirements for the lifetime extension are to be reduced, which automatically leads to an increase in risk.

Due to the retrofits carried out so far, Doel-4 and Tihange-3 do not reach the safety level of new plants, design deficits relate to the area of beyond design basis accidents. Instead of technical upgrades, only measures by the operating team have been introduced so far. **To prevent a massive radioactive release, the operating team would have to try to prevent a serious accident under adverse conditions and essentially with mobile devices.** Note: In Sweden, reactors of the same type have been retrofitted with an independent core cooling system.

The most important safety goal for new nuclear power plants is the exclusion of core meltdown accidents with early and high releases. So far, this safety requirement has not been met for Doel-4 and Tihange-3. This fundamental safety objective must be met by new nuclear power plants. In the case of existing plants, on the other hand, it is conceded that the implementation of the requirements may not be "reasonably feasible". It therefore remains the task of the supervisory authority to check to what extent the planned measures are sufficient to meet the requirements for the necessary protection of the population. **The population and politicians have a right to know what deficits Doel-4 and Tihange-3 have compared to the current security requirements. Furthermore, they should receive information about which upgrades would be technically possible but should not be carried out for economic reasons.**

Unlike in France, where the current safety targets are used as the standard for retrofitting to extend the life of the old reactors in the 900 MW class, no attempt is made in Belgium to meet these requirements as part of the planned life extension.

As recommended by WENRA, Doel-4 and Tihange-3 should be checked for the lifetime extension as part of the PSR to determine the extent to which they meet the applicable safety targets for new reactors. Only on this basis can the supervisory authority decide whether continued operation for Doel-4 and Tihange-3 can be approved or whether the risk to the population is too great.

5 dangers from natural events

The EIA documents contain only very general information on the design of Doel-4 and Tihange-3 against the effects of natural hazards and the protection of the facilities against such effects.

earthquake

The EIA documents do not contain seismic hazard and seismic protection information. The probabilistic seismic hazard analysis (PSHA) within the framework of the European stress tests determined a significant increase in the intensity of the design basis earthquake (DBE): For the Tihange site, the value of the peak ground acceleration (PGA) increased from 0.17 g to 0.23 g (increase of 35 %), for the Doel site from 0.056 g to 0.081 g (45%). The EIA documents do not state whether all the necessary upgrades have been carried out or whether they are required for the extension of the service life. **Experience has shown that the use of components that do not conform to the specifications and assembly errors with retrofitting in some cases only theoretically achieve the required level of safety.**

In order to mitigate the risk of internal flooding caused by earthquakes, the following measures are required for Doel-4 and Tihange-3: A person must run to the cooling tower as soon as possible after an earthquake to check whether it overflows, in which case the Pumps can be switched off quickly. (FANC 2011) **This is just one example of many where design flaws in the facilities have to be remedied by the actions of the operating crew.**

Danger of flooding for the Tihange nuclear power station

The EU stress test made it clear that possible flooding events could lead to a severe accident with massive radioactive releases. The application of the probabilistic approach according to international standards [26]led to new DBF parameters. The water levels determined would significantly exceed the platform height at the site (up to 1.70 m), which would lead to the three blocks being flooded and the safety-relevant systems being completely lost and thus to a core meltdown accident. (FANC 2011)

The measures designed for the upgrade initially included three so-called lines of defense: peripheral protection of the site (first line of defense), local volumetric protection of the buildings (second line of defense), use of mobile non-conventional means on site (third line of defense).

The newly built peripheral protection of the site consists of a *flood protection system (flood protection wall, dyke, non-return valves)* . Electrabel planned to build a wall no higher than the water level of the DBF. FANC requested a safety margin to account for uncertainties in the calculation. The safety margin is not known. **It can therefore not be ruled out that the protection will be insufficient for the future.**

This is particularly relevant as the implementation of building protection (2nd line of defense) has been abandoned and the 3rd line of defense offers little protection:

If conventional means are no longer available due to flooding, the non-conventional means (NCM) pre-installed in the alerting phase should be used (3rd line of defence). These consist of additional mobile diesel generators and pumps. However, it will be very difficult for the operating crew to prevent a core meltdown accident involving mobile equipment. *Personnel actions are further complicated by the need to use boats (amphibious vehicles) to transport personnel and equipment.* **This is an irresponsible approach, especially given the increasing risk of flooding due to the effects of climate change. Overall, there is a risk of flooding at the site.**

There is also a risk of external flooding in the event of severe flooding of the Meuse north of the Tihange site, an accidental rupture of the Ampsin-Neuville dam or an overflow of the air coolers at Tihange 2 and Tihange-3. A protective dam was built to avoid the risk of flooding. (SCK CEN 2023a)

Danger of flooding for the Doel site

The most important protective measures to minimize the risk of flooding are the elevated position of the site and the dyke that limits the site to the river Scheldt. [27]The dyke height is also considered sufficient in connection with the expected rise in sea level due to climate change. (SCK CEN 2023a)

However, the site can be flooded if a very high Scheldt level and a dike breach occur at the same time. A dyke failure at the most critical point of the dyke is not so improbable. [28]In this scenario, the water would reach the first buildings very quickly (after about an hour), water levels of up to 60 cm could occur locally. The site, which is on a raised platform, would become an island.

In this case, the volumetric protection (second line of defense) must hold at all costs. A ll buildings and basements in which safety-related systems and components are housed, as well as all underground lines leading to these buildings and basements, must be protected or sealed in such a way that no water can penetrate. **Experience shows that such seals can fail in particular due to aging but also at higher water levels.**

Extreme weather conditions

The EU stress tests showed that the design parameters for extreme weather conditions for the Belgian nuclear power plants were mainly based on historical data and thus on a return period of the order of 100 years. One lesson learned from the Fukushima accident was that protection against natural hazards

[26]to calculate a flood rate with a return period of 10,000 years (3488 m^3/s)

[27] During the construction of the nuclear power plant, a platform was erected at a height of 8.86 m TAW. The dike has a height of 12.08 m TAW. The design high water was later increased to 9.35 m TAW.

[28]return period of 1,700 years

must be significantly improved. A facility must therefore be protected against the identified natural hazards and hazard combinations based on events with an average repetition period of 10,000 years .

The EIA report addresses the vulnerability of the project to the impacts of climate change (e.g. in the form of droughts, floods...). It explains that the signs of climate change have become increasingly clear in recent decades and especially in recent years. The developments that have been forecast and have already been identified will continue and also become more intense. Therefore, within the reference period of the project, the following must be taken into account (SCK CEN 2023a):

- higher average temperatures, with milder winters and warmer summers;
- more frequent heat waves, which can also be more intense and last longer;
- an increase in total annual precipitation, with more rain in winter and possibly more flooding),
- an increase in peak precipitation intensity of short, intense showers that can cause flooding;
- a rise in sea level, with consequent greater risk of flooding along the coast and estuaries;
- higher wind speeds.

The EIA report explains that most projections are for the future, such as the year 2050 or even 2100. Such reference years would logically not be relevant for the present project. For Doel, the information from the VMM climate portal is used, which contains some parameters for the year 2030, which can be considered representative for the average situation in the period 2027-2037 (SCK CEN 2023a). **A technical justification for this implausible assumption is not given.**

Extreme rainfall

Electrabel carried out a reassessment of the impact of heavy rainfall in Doel as part of the 2011 stress tests. The EIA report explains that intensities have indeed increased since then (and certainly by 2037), so the likelihood of such situations occurring as well as the magnitude of the consequences may of course increase as well. Considering the relatively high return period used and the fact that no critical functions are threatened by a potential flood, the significance of this impact is assessed as low. (SCK CEN 2023a)

For Tihange, too, it is assumed that the assumption of a return period of 10,000 years is sufficient to take into account the risk development associated with climate change. No major problems are expected in the future as a result of climate change with more intense precipitation. (SCK CEN 2023a) **A reassessment is apparently not planned; whether critical functions are actually at risk can only be assessed after a corresponding analysis. In particular, there may be a hazard in combination with other external events.**

Extreme temperatures

Extreme temperatures were also taken into account in the design basis and in the dimensioning of the equipment. As part of the preparation for extending the life of Doel-4, it was determined that dealing with potential heat waves could lead to design improvements (e.g. adding air coolers or humidifiers in rooms). Increasing the systems' resilience to the effects of extreme temperatures as a result of climate change is therefore integrated into the project from the outset. (SCK CEN 2023a) Regarding climate change , it is the only change envisaged. For Tihange it is explained: Since no problems have occurred in recent years with sometimes very hot summers, it is assumed that this will also be the case for the period 2025-2037. (SCK CEN 2023a)

Higher average temperatures

It should also be noted that for Doel it is stated that the temperature of the discharged cooling water must not normally exceed 30°C, but a separate emission limit value of a maximum of 33°C applies to power plants. This limit does not have to be applied if, in the event of exceptional meteorological circumstances (heat wave), network security is at risk. However, heatwaves leading to higher discharge temperatures will become more frequent in the future, making the "extraordinary meteorological circumstances" much less extraordinary. In this context, it is explained for Tihange-3 that the high average values have a negative effect on power generation. (SCK CEN 2023a)

Strong wind and tornado

The maximum wind speed of 49 m/s, which served as the design basis for all buildings, has never been measured in Belgium. The interpretation of Doel-4 and Tihange-3 takes into account a reference tornado that has never occurred in this region. [29]According to the EIA report, important safety-critical buildings can also withstand tornadoes that are stronger than the reference tornado. However, extreme wind speeds or tornadoes can result in a partial or complete loss of external power supply (LOOP). (SCK CEN 2023a) In combination with other flooding events, these could result in a dangerous situation.

Hazard Combinations

According to WENRA (2015), relevant hazard combinations must also be identified to protect against natural hazards. As part of the Doel 1&2 life extension EIA process, it was stated that the assessment of the Doel site's combination of hazards applicable to ANSI (1978) had been completed. However, this is an outdated standard that was withdrawn by the American Nuclear Society in 1988. **Up to now, current WENRA requirements and guidelines have not been taken into account for the analysis of hazard combinations** . It was therefore recommended to consider current requirements (WENRA 2021) and guidelines (WENRA 2015; DECKER & BRINKMAN 2017) for the analysis of site-relevant hazard combinations. (UBA 2021)

5.1 Conclusions and Demand

WENRA (2011) calls for possible effects of natural hazards to be checked as part of the periodic safety reviews that take place every 10 years. If necessary, the results of the review should lead to an adjustment of the design basis of the plant and be included in the assessment of beyond design basis accidents. However, it is not clear from the EIA documents whether this process is to be carried out as part of the life extension for Doel-4 and Tihange-3. On the contrary, the wording suggests that a reassessment will not be carried out.

With regard to extreme impacts, the negative changes caused by climate change are mentioned, but at the same time the reassessment after the 2011 stress test is considered sufficient for the period up to 2037. If the flood protection system in Tihange fails, the area will be flooded, the safety systems will fail and the operating team will have to use mobile equipment from boats to prevent a core meltdown accident. A dyke breach can also lead to a dangerous situation.

In view of the existing and increasing danger from extreme natural events, the risks must be reassessed, which also takes climate change into account appropriately, instead of relying on the supposed existing safety reserves.

6 Dangers from terrorist and military acts

The EIA documents do not address the risk of military or terrorist acts. This is inappropriate given the general vulnerability and the specific threat in Belgium.

Sabotage of Doel-4's steam turbine and dangerous espionage

On August 5, 2014, information became known about an act of sabotage that caused significant damage in Doel-4. Lubricant had escaped from the high-pressure turbine through a valve. Since this valve was opened intentionally but without any instructions to this effect, **sabotage is** assumed. Electrabel filed a complaint against unknown persons and joined the proceedings as a joint plaintiff. In early 2022, federal

[29]107.3 m/s, while in Belgium a maximum of 70 m/s is considered possible

prosecutors dropped the investigation because they did not have enough evidence to identify the perpetrator or perpetrators.

In order to prevent such an incident from happening again, FANK has imposed a series of additional safety measures on all nuclear power plants in Belgium. These measures included, among other things, the installation of additional cameras, changes to the service ID access system and the extension of the scope of the four-eyes principle. In 2020, FANK, together with a number of international partners, founded the *"Insider Threat Mitigation" working group* to develop a targeted strategy to combat insider threats in nuclear facilities. (FANC 2023a)

In late 2015, it was revealed that the home of a senior official in Belgium's nuclear sector was being spied on by people linked to the perpetrators of the November 2015 Paris attacks. Even if there was no concrete indication of an attack, the entire Belgian nuclear sector was on high alert. The Belgian government then decided to set up a specialized surveillance and protection corps within the Belgian State Police to protect the nuclear installations in Belgium. [30](FANC 2020a) After the terrorist attacks of March 22, 2016 in Brussels and Zaventem, FANK decided to maintain all supplementary security measures.

threat from insiders

The implementation or support of a terrorist attack by internal perpetrators represents a major threat to nuclear power plants. This problem has received a great deal of attention in international specialist discussions in recent decades. Reliability tests regulate the verification of people who work in nuclear facilities. These make it more difficult for insiders to smuggle in, but they do not prevent it completely. One of the most important protective measures against attacks by insiders is the four-eyes principle. However, this is always ineffective if several active insiders act. It can also be subverted by carelessness, sloppiness, or generally by a poor safety culture.

This danger must be assessed as high for Belgium, as shown by the sabotage in Doel-4, which has not been clarified to this day. According to the Nuclear Security Index, the requirements for protection against insiders and the security culture are also insufficient, which increases the danger **. The measures taken after the sabotage in Doel-4 correspond to the standard measures, which are not sufficient.**

Nuclear Threat Initiative (NTI)

A current assessment of nuclear security in Belgium indicates deficits compared to the necessary requirements for nuclear security: In the so-called Nuclear Security Index 2020, the US Nuclear Threat Initiative (NTI) evaluated the measures that countries take to protect against terrorist attacks and sabotage their nuclear facilities. In the Nuclear Security Index, 100 corresponds to the highest possible score. Belgium is 16th out of 47 countries with a total score of 80 points. It shows low scores for "security culture" (50), "cybersecurity" (50) and "protection against insider threats" (55). **These low scores indicate weaknesses in protection.** (NTI 2021)

Cyber Attack Threat

Recently, cases have become known in which computer viruses were introduced from outside into industrial and even into the computer systems of nuclear plants. Through targeted program changes, it is basically possible to change the control and regulation equipment in nuclear power plants in such a way that adequate cooling of the reactor core is prevented (MAJER 2013). In 2012, Engie stated that a cyber attack cannot lead to the loss of safety functions in a Belgian nuclear power plant. However, according to FANC, the aspects of cybersecurity and the technologies associated with it are constantly evolving, so that the security aspects must be checked regularly. **According to the Nuclear Security Index, the requirements for protection against cyber attacks show deficits.**

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[30]Pending the effective creation of this specialized police corps, soldiers will be deployed to support the police at Belgian nuclear sites.

Threat of attacks from the air

In 2011, the Belgian supervisory authority demanded that terrorist attacks as possible triggers for serious accidents should also be integrated into the Belgian stress test program (FANC 2011). One result of the investigation was that in the event of an airliner crash, no dangerous damage can occur to the dual containment of Doel-4 and Tihange-3. It is further explained that the second level security systems are located in bunker buildings that are spatially separated from the first level security systems. It is therefore almost impossible for a plane crash to cause the systems of both planes to fail at the same time. (FANC 2012a)

According to WENRA (2013), it is expected for new nuclear power plants that a targeted crash of a commercial aircraft will not lead to a core meltdown accident, and therefore may only have minor radiological consequences according to the WENRA safety target (O2). In order to prove this, effects from direct and secondary effects of the aircraft accident are to be considered (vibrations/shocks, burning and/or explosion of the aircraft fuel). In addition, buildings containing security systems and nuclear fuel should be designed so that no kerosene can penetrate.

The design of Doel-4 and Tihange-3 does not meet the current requirements for several reasons.

- In the above-mentioned investigations by the Belgian supervisory authority, the investigations into vibrations were probably not sufficiently considered, so that serious damage to the primary circuit, which could cause a core meltdown accident, cannot be ruled out.
- Aging effects must also be taken into account: A current study uses numerical simulations to examine the influence of aging on the effects of a military aircraft impacting a nuclear power plant. The results show that the aging of a facility increases the susceptibility to widespread or localized penetration. For the same impact force, the strength of the aged containment is reduced by approximately 30%. (FRANCO 2021)
- The buildings containing the second level security systems are designed to withstand the impact of a small civilian aircraft of approximately 90 tons traveling at approximately 306 km/h. (INRAG 2021) In Doel-4 and Tihange-3 there was also damage to buildings due to manufacturing and aging. In this respect, it cannot be completely ruled out that a commercial aircraft crash would lead to a serious accident.
- In addition, the penetration of kerosene into the buildings for storing the spent fuel elements cannot be ruled out, as these are not protected against extreme external influences.

In addition to an attack with a commercial aircraft, a number of other attack scenarios are conceivable for a terrorist attack from the air. Scenarios for terrorist attacks from the air can e.g. B. the crash of a helicopter loaded with explosives or the dropping of a bomb from the helicopter. The drone overflights in France in autumn 2014 highlighted weaknesses in the air surveillance of French nuclear power plants and, above all, in the defense against such potential attacks from the air. In autumn 2014, a total of 31 drone overflights were recorded over 19 French nuclear facilities. [31]For example, drones can B. - be used to prepare or support a terrorist attack - as in the military application. (GP 2014) The same deficits in terms of an attack from the air exist in other countries as well as in Belgium.

military actions

With the targeted terrorist attack on September 11, 2001, it became clear that extreme terrorist activities can also pose a concrete threat, which led to a tightening of safety requirements for nuclear plants. With Russia's attack on Ukraine, however, scenarios have emerged that were previously considered hardly realistic. The risk of catastrophic accidents has increased again. Russia has made it clear that international rules prohibiting acts of war involving nuclear power plants can only last as long as all actors feel bound by them. In such cases, nuclear facilities become a particular threat. (BASE 2022)

[31] It is still unclear who piloted the drones.

The protracted war in Ukraine leads to the further proliferation of military weapons and, consequently, to an increase in the risk of terrorist attacks.

6.1 Conclusions and Demand

Terrorist attacks and acts of sabotage can have a significant impact on nuclear facilities and cause serious accidents - including for Doel-4 and Tihange-3. This applies in particular to the threat situation in Belgium presented. Yet they are hardly mentioned in the EIA document. Such events have been discussed to some extent in comparable EIA documents.

Although the Doel-4 and Tihange-3 plants are better protected than even older plants, their level of protection shows deficits compared to the level of protection expected today. In addition, the requirements in Belgium for such protection do not meet the currently required requirements.

The special threat situation in Belgium and the insufficient protection of the Doel-4 and Tihange-3 plants against terrorist attacks and acts of sabotage should play a decisive role in an assessment of the risk for the population by extending the operating hours.

7 Impact of a major accident on Belgium and neighboring countries

Accidents calculated in the EIA documents

Two design basis accidents and one beyond design basis accident are calculated in the EIA documents (SCK CEN 2023a). One of the two design basis accidents is a so-called LOCA (loss of coolant accident), the other a fuel element handling accident (FHA). A complete station blackout with core meltdown (CSBO) was assumed to be the beyond design basis accident.

The following tables show the calculated dose values for these three accidents in Belgium. For the design basis accidents, results from two different investigations are used. On the one hand, these are the results of the safety analysis for the respective nuclear power plant based on the general data in accordance with the Euratom Treaty Art. 37 from 1981, and on the other hand an analysis based on the guidelines from 2017 for new nuclear facilities from FANK and Bel- V (which, according to the EIA report, are not actually applicable to Doel-4 and Tihange-3 since they are not new plants). These two calculations differ in the methodology of the dispersion calculation and the use of newer dose coefficients. Both variants are shown in the following table, the results of the analysis according to the guidelines from 2017 are in (brackets); they are consistently lower because the underlying assumptions are less conservative.

Table 3: Dose calculations from SCK CEN (2023a) for the design basis accidents and the beyond design basis accident in Doel-4 outside the site boundary of the nuclear power plant, approx. 300m from the discharge point (calculation results according to guidelines from 2017 in brackets)

	LOCA	FHA	CSBO
effective dose	20.4mSv (2mSv)	5.7mSv (2.8mSv)	8.89 mSv
Thyroid Equivalent Dose	38.5mSv (36.7mSv)	33.28mSv (24.7mSv)	0.4 mSv

Table 4: Dose calculations from SCK CEN (2023a) for the design basis accidents and the beyond design basis accident in Tihange-3, up to 1000 m outside the site boundary of the nuclear power plant (calculation results according to guidelines from 2017 in brackets)

	LOCA	FHA	CSBO
effective dose	5mSv (0.89mSv)	1.16mSv (0.35mSv)	4.29 mSv
Thyroid Equivalent Dose	4.91mSv (1.45mSv)	22.5mSv (4.95mSv)	0.033 mSv

Calculations of dose levels in other countries are presented in SCK CEN (2023a) for Tihange-3. Effective doses of more than 0.6 mSv are not calculated for either design basis accidents or beyond design basis accidents. The thyroid equivalent doses are below 0.3 mSv. The dose values calculated for Doel-4 in neighboring countries are not listed.

At what dose levels must interventions start? This is different in different countries. The table below provides an overview of intervention values in Belgium and neighboring countries.

Table 5: Comparison of dose guidelines and intervention measures in Belgium and its neighboring countries, plus Austria, Source: HERCA Country Fact Sheets, www.herca.org)

intervention measure/country	type of dose	Belgium	Netherlands	Luxembourg	France	Germany	Austria
Sheltering	Effective dose in mSv (children and pregnant women/adults)	5	5-10	10	10	10	1/10
Administration of potassium iodide tablets	Thyroid equivalent dose in mSv (children and pregnant women/adults)	10/50	10-50/ 50-250	50	50	50/250	10/100
evacuation	mSv (usually over 7 days)	50	50-100	100	50	100	50
Temporary relocation	mSv in a month						30
Permanent resettlement	mSv in one year						100

Depending on the assumed accident and the type of calculation, a dose can be reached that triggers intervention measures.

The table above shows that the same intervention measures are linked to different dose benchmarks in different countries. This leads to confusion, especially in the report close to the border, where there is usually a lot of commuting. A harmonization should be aimed at, namely at the lowest reference values, in order to be able to keep the effects of radiation through intervention measures as low as possible.

Even the design basis accidents have consequences for agriculture

In the event of an impending contamination of agricultural land, protective measures must be taken to reduce the uptake of radionuclides by animals and plants. When these measures start again varies from country to country.

- In Doel-4, 220 kBq I-131/m ^{2} (LOCA) and 925 kBq I-131/m ^{2} (FHA) are calculated for the two calculated design basis accidents. For Cs-137, the calculated contamination remains at around 9 Bq/m ^{2}. A contamination with I-131 of more than 4 kBq/m ^{2} is also assumed for the beyond design basis accident (the calculated value is not specified); No information is given on the deposition of Cs-137 for the beyond design basis accident.
- In Tihange-3, the calculations for the design basis accidents result in 20.5 kBq I-131/m ^{2} (LOCA) and 65 kBq I-131/m ^{2} (FHA). For Cs-137 the contamination is about 23 Bq/m ^{2}. No information is provided for the beyond design basis accident.

It is not explained at what distance from the reactors these levels of contamination occur. With regard to Doel-4, however, SCK CEN (2023a Chapter 7.6) notes that iodine contamination above 4 kBq/m ^{2} can also occur in the Netherlands and Germany.

In the case of the calculated design basis accidents in both reactors, countermeasures would have to be taken in Belgium due to the iodine contamination, as these exceed the Belgian derived contamination values for milk (4 kBq I-131/m^2), vegetables (10 kBq ^{I}-131/m^2) and meat (40 kBq I-131/m^2). The derived Cs-137 values of 6 or 10 kBq/m^2 are not exceeded. According to the EIA documents, it is expected that the harvest could fail for a year.

It should be borne in mind that the calculated accidents are not the most serious possible, so in the event of a serious accident involving a containment bypass, agricultural measures could be necessary in large areas, even outside of Belgium.

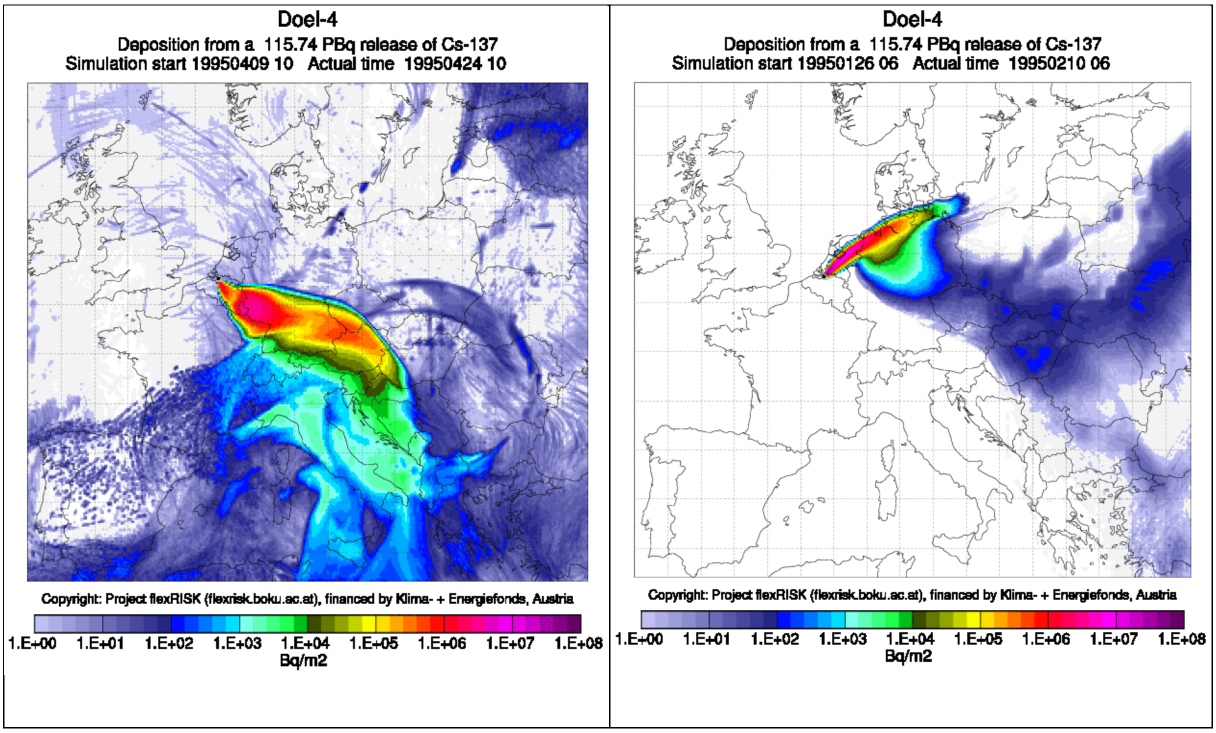
Furthermore, the values for the start of agricultural countermeasures in Belgium are higher than in Austria, for example, where measures start at an iodine contamination of 700 Bq/m^2 .

The worst possible accident?

The accidents considered in the EIA report are by no means the worst possible accidents.

Research project flexRISK , in which the risk of severe accidents in nuclear power plants in Europe was examined, [32]is used here as a comparison . Based on source terms, an up-to-date dispersion model was used to calculate Cs-137 and I-131 soil contamination and doses for approximately 2,800 different weather situations. Furthermore, the Cs- 137 deposition was determined for 88 real weather scenarios of a representative year (1995). The results were visualized in maps. For Doel-4, flexRISK used a release of 115.74 PBq Cs-137 and 726.2 PBq I-131 for the calculations, and for Tihange-3 103.87 PBq Cs-137 and 810.87 PBq I-131. Such source terms can result from a severe ISLOCA accident and are comparable to the release from Chernobyl [33].

The figure below shows the flexRISK results for the same assumed severe accident, but on four different days and thus in four different weather situations; this for Doel-4 and for Tihange-3.



[32] http://flexrisk.boku.ac.at/en/index.html

[33]Release in the Chernobyl accident according to various literature sources approx. 78-112 PBq Cs-137.

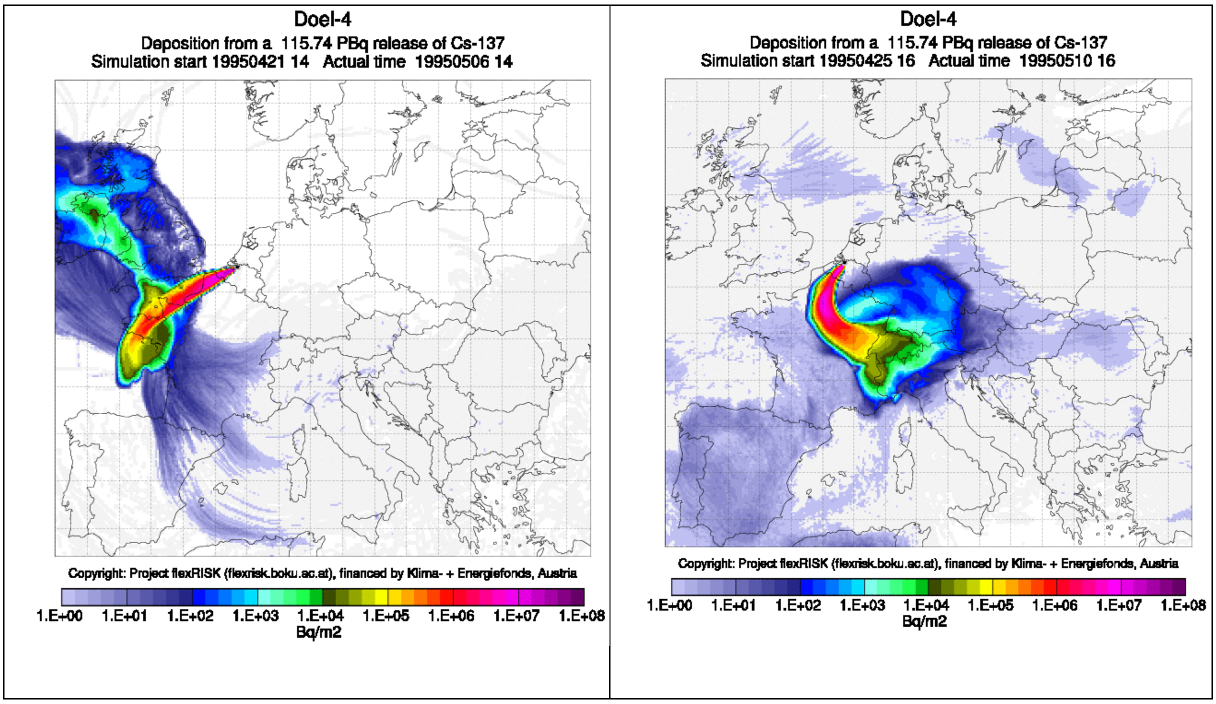
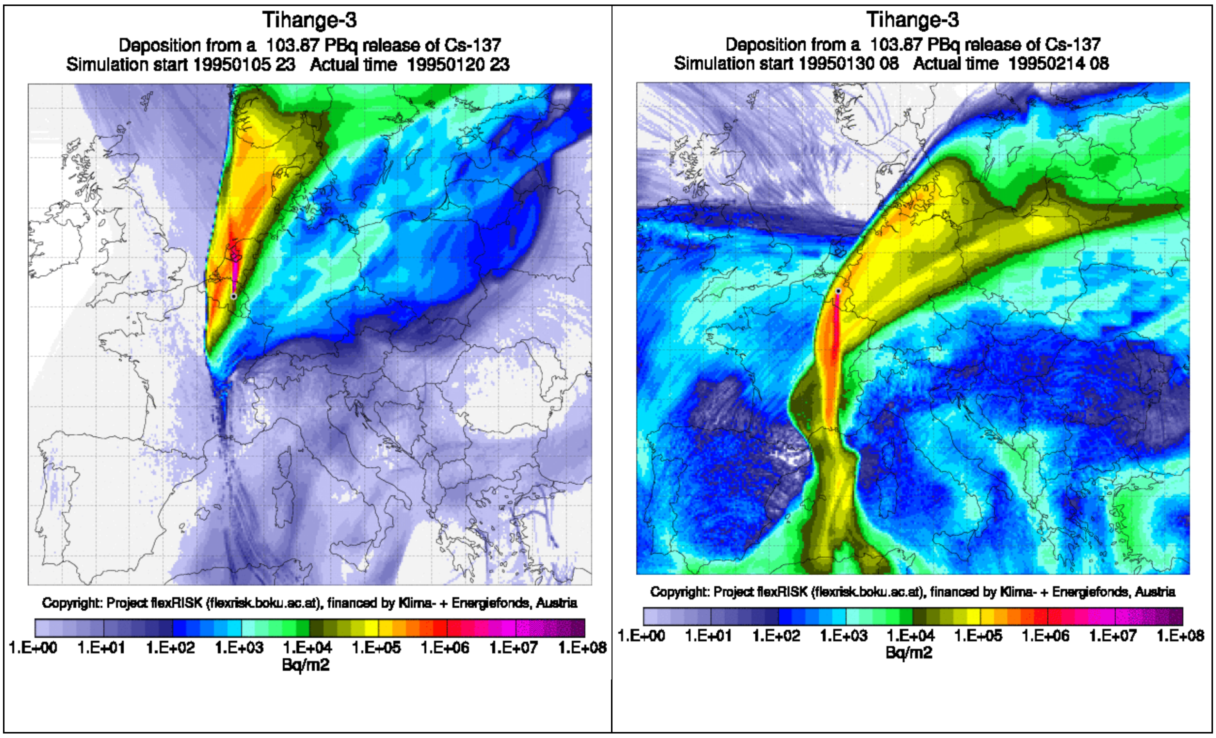


Figure 1: Major accident contamination at Doel-4 in Bq Cs-137 per m ^{2} *. Source: flexrisk.boku.ac.at.*



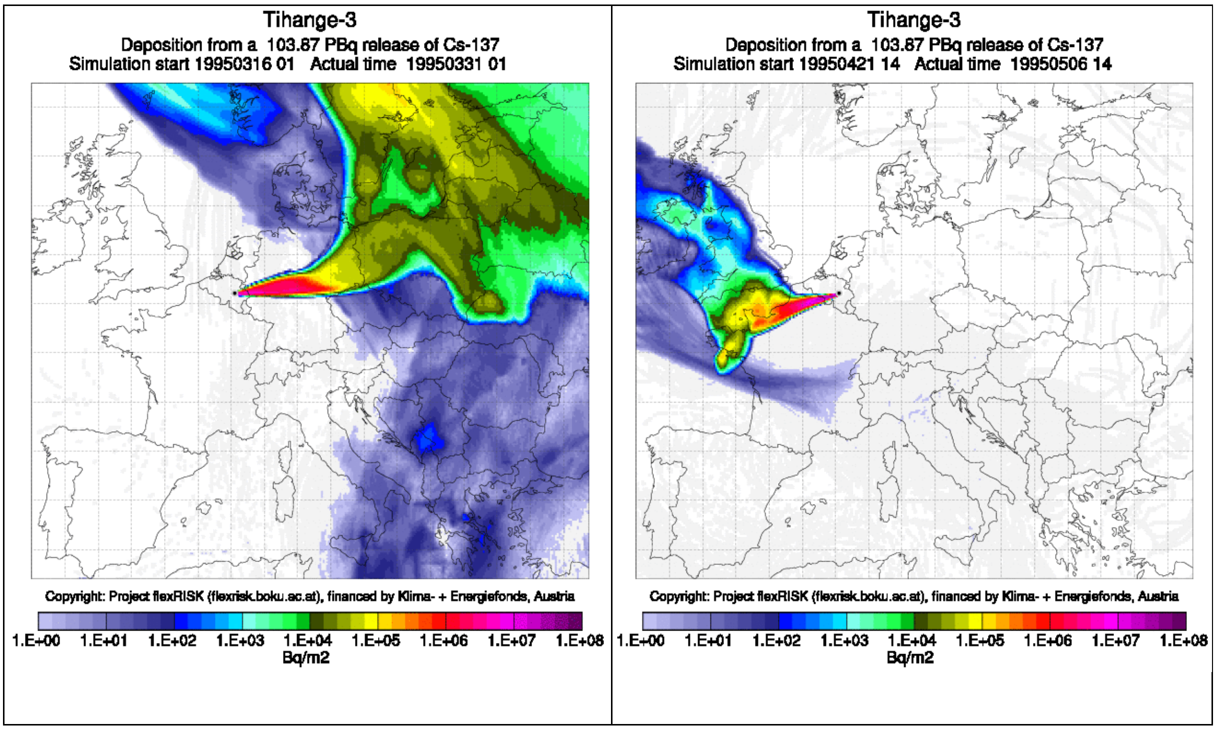


Figure 2: Major accident contamination in Tihange-3 in Bq Cs-137 per m ^{2}. Source: flexrisk.boku.ac.at.

For comparison: the maximum contamination with Cs-137 in Belgium, Luxembourg and the Netherlands after the Chernobyl accident was 10 kBq/m ^{2}, which in the figure above corresponds to the light green area up to 1E+04 Bq/m ^{2}. In France it was a little higher at a maximum of 20 kBq/m ^{2} (olive green area), in Germany however at a maximum of 100 kBq/m ^{2} (dark yellow, 1E+05 Bq/m ^{2})

After Chernobyl, areas in the former Soviet Union with a deposition of 37 kBq Cs-137/m ^{2} or more were defined as "contaminated" and subjected to continuous monitoring; People in areas with a contamination level above 185 kBq Cs-137/m ^{2} had the right to relocate, and areas with a contamination level above 1,480 kBq Cs-137/m ^{2} were relocated. (In the figures above, a contamination of 185 kBq/m $^{2\ \text{corresponds}}$ to the orange area and 1,480 kBq Cs-137/m ^{2} to the purple area.)

It is easy to see that the possible contamination from this assumed serious accident depends heavily on the weather. **Due to the weather conditions, large parts of Europe can be affected, as can be seen from the location and size of the orange, red and purple areas. For example, the radioactive cloud from a severe accident in Doel-4 would initially move to the south-east (via Luxembourg) under weather conditions like those of April 9, 1995, then move on via central and southern Germany, turn off via the Czech Republic, Austria and Switzerland and move on to Italy .**

If all individual weather situations are superimposed, weather-related probabilities are obtained as to which areas of Europe could be contaminated with more than 37 or 1,480 kBq Cs-137/m 2 in the event of a severe accident in Doel-4 or Tihange- 3 .

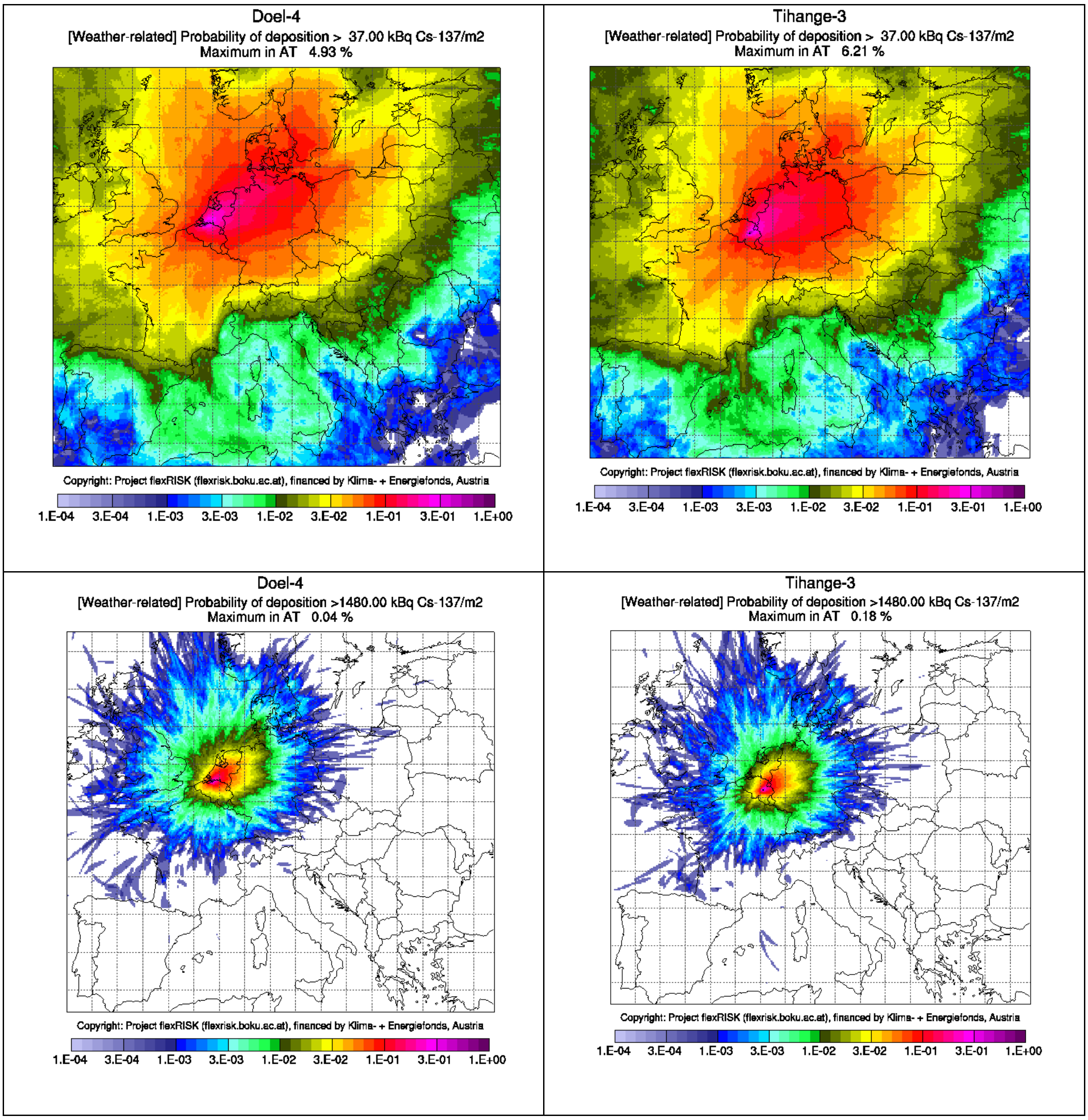


Figure 3: Weather-related probability of being contaminated by a severe accident in Doel-4 and Tihange-3 with more than 37 and 1,480 kBq Cs-137/m ^{2}*. Source: flexrisk.boku.ac.at.*

The scale ranges from 1E-04 (probability of 0.01%) to 1E+00 (probability of 100%) – the latter concerns the areas in the immediate vicinity of the nuclear power plants.

Areas northeast of the relevant nuclear power plants have the highest weather-related probability of being contaminated by a severe accident, this is the most common wind direction. **The two lower figures (probability of contamination with 1,480 kBq Cs-137/m** ^{2}**) show which areas have a high probability of having to be evacuated in the event of the assumed serious accident; these are by no means only areas in Belgium, but also in the neighboring countries, with a higher probability in the north-east direction.**

7.1 Conclusions and Demand

The accidents calculated in the EIA documents (design basis accidents and beyond design basis accidents) can lead to intervention measures such as sheltering (staying indoors) or the administration of potassium iodide tablets having to be ordered in Belgium. Furthermore, both the design basis and the beyond design basis accident can lead to agricultural measures having to start.

However, it must be taken into account that these calculated accidents are by no means the worst possible accidents. **In the flexRISK project, a possible accident with containment failure was calculated for both reactors. These results show that large parts of Europe could become contaminated** . Areas northeast of the relevant nuclear power plants have the highest weather-related probability of being contaminated by a severe accident. **Such an accident could even result in areas in and around Belgium having to be resettled** .

The transboundary impacts for a major accident should be calculated in the EIA process, regardless of the estimated probability of occurrence, as long as it is physically possible in order to clarify the risk. The results of the flexRisk project determined the massive impact of such an accident for Belgium and Europe.

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