The construction of the nuclear power plant Hanhikivi 1 – implications for Bothnian Bay fauna

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Abstract
Fennovoima AB plans the construction of a nuclear power plant (Hanhikivi 1) with a capacity of 1200 MW on the headland of Hanhikivi in Pyhäjoki district, Finland. The project has been approved by the Finnish government and today the area is closed for the general public. Construction is planned to start late in 2016. Intake and discharge of cooling water occurs directly from Bothnian Bay. Its brackish water environment, a low species richness and a limited water exchange between the Bay and other parts of the Baltic Sea are the main reasons for the Bay’s vulnerability to environmental changes and anthropogenic influences. Effects will mainly be a consequence of the heating of the water around the discharge as well as through increased nutrient load and input of radionuclides. Locally, cold water species will decrease while warm water species will be favoured by the increasing water temperatures. Radionuclides are taken up by flora and fauna and can be bioaccumulated in both fish and marine mammals.

KEYWORDS: Aquatic environment, bioaccumulation, Bothnian Bay, caesium, Hanhikivi, nuclear power plant, radionuclides

Sammanfattning

Nyckelord: Bottenviken, bioackumulation, cesium, Hanhikivi, kärnkraftverk, radionuklider, vattenmiljö
Acknowledgements

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Abbreviations

NPP Nuclear Power Plant
PWR Pressurized Water Reactor
BWR Boiling Water Reactor
Bq Becquerel (kBq = 1E3, MBq = 1E6, TBq = 1E12)
1 INTRODUCTION

Nuclear power is and has long been a topic of heated discussions. While European countries like Germany try to get along without nuclear power in the near future; others like Finland are building new reactors (Susanto 2013). In 2011, Hanhikivi headland in Pyhäjoki was chosen as location for the third nuclear power plant (NPP) in Finland. The project has recently been approved by the Finnish government and construction is expected to start in the end of 2016. In the writing hour, the area for the planned NPP Hanhikivi 1 is already closed for the public by Fennovoima, which is entrusted with the construction of Hanhikivi 1 (Fennovoima 2014; 2016).

Radionuclides occur naturally in the environment as background radiation. Artificial radionuclides however harm the environment and do so under a long period of time due to their long half-lives and in some cases their potential for bioaccumulation (Steinhauser et al. 2014; Apte 2012). Consequently, there are different “safe exposure values” defined for humans. Due to the lack of research however uncertainty remains about the effects of smaller dosages emitted to the environment (Jha et al. 2012; Batlle 2011).

Even though there are different types of NPP, their discharges during normal operation are similar and include radionuclides (Lünig et al. 2009; Zakaria et al. 2008). Many NPP are located in coastal areas. Consequently, their impact on the aquatic environment is an important issue that should be studied in more detail. In the Baltic Sea region there are three NPP at the Swedish, two at the Finnish and one at the Lithuanian coast (HELCOM 2009b). Nowadays, the main sources of artificial radionuclides (especially $^{137}$Cs) are those emitted by the Chernobyl accident in 1986 and during nuclear weapons test in the 1950s (HELCOM 2013; Iosjpe et al. 2014). The two most recent nuclear disasters, Chernobyl and Fukushima caused contamination of atmos-, hydros-, pedos- and biosphere over large areas in the entire northern hemisphere (Steinhauser et al. 2013). Questions about environmental consequences for Hanhikivi remain.

Bothnian Bay is the northernmost part of the Gulf of Bothnia. With an area of almost 37 000 km$^2$ the Bay receives most of its water through inflow from Finnish and Swedish rivers. The region is characterised by a steady land uplift and covered by ice several months each year. Containing brackish water, species composition is different and much lower than normally the
case in freshwater and marine ecosystems (Håkansson et al. 1996; Wulff et al. 1996). Ecosystems consisting of only a few species are relatively fragile and vulnerable to stress. In aquatic systems stress can be fishing, destruction of habitat and/or water pollution (HELCOM 2010a). In addition, the young geological age (around 2000 years) and the still ongoing changes in species composition contribute to its susceptibility. Disturbances of the system can therefore lead to significant consequences for the whole food web (Laamanen 2013; HELCOM 2010a).

The aim of the present study was to evaluate potential impacts of Hanhikivi 1 for the fauna of Bothnian Bay. Special features in the Bay’s oceanography, the current status of contamination and species composition are described. More shortly, the site and project for the NPP construction on Hanhikivi is accounted for. Research is needed as Hanhikivi 1 will be the first NPP along the especially vulnerable Bothnian Bay coast. After the description of radionuclide discharges, focus lies on the effects of the need for cooling water and the potential for bioaccumulation of radionuclides. Finally, the Environmental Impact Assessment performed by Fennovoima is shortly presented and discussed and further research needs are indicated.

2 MATERIALS AND METHODS

The present study consists of a review of existing research on the impact of building and normal operation of nuclear power plants. Furthermore, special features from Bothnian Bay, like species composition and current status of contamination were researched. The aim was then to evaluate impacts on Bothnian Bay fauna as a result of the building and operation of Hanhikivi 1. The impact on flora is an important question as well; because of the limited space in this study however, it could not be taken up in a more thorough way. Initially, the intention was to perform a risk assessment as well. However, it was realized that this would result in the work for two research papers. Partially, this is a consequence of the small amount of scientific research done on NPP impacts on aquatic environments and especially the impacts of smaller amounts of radionuclide discharges.

For the literature review, books and scientific articles from the past 20 years were researched. Databases such as Science Direct, Scopus, Web of Science and Google Scholar were searched
for information on Bothnian Bay characteristics as well as on environmental impacts of effluents/containments from NPP situated close to water bodies. Among other, search words were Bothnian Bay, nuclear power plant, Hanhikivi, radionuclides, contamination fauna, marine environment, cooling water and nuclear power plant, discharges nuclear power plant, environmental impact assessment NPP and bioaccumulation. Measurements from the Baltic Sea after the Chernobyl accident helped the understanding of radionuclide behaviour in aquatic environments. The main source of impacts of cooling water intake and discharge were derived from Sandström (1990) and the experiences of 10 year measurements at the Forsmark NPP in southern Sweden.

3 RESULTS

3.1 Bothnian Bay

3.1.1 Oceanography

Bothnian Bay (see fig. 1) is situated between 63.5 °N – 66.0 °N, between Sweden and Finland. The shallow Quark divides Bothnian Bay and Bothnian Sea; restricting the water transport between them (Håkansson et al. 1996). Bothnian Bay has an area of 36 800 km² and an approximate water volume of 1490 km³. Average sea surface temperature lies between 5 °C and 6 °C (Stramska, Białogrodzka 2015). The region is characterized by a continuous land uplift (Furman et al. 2016).

The Bay’s drainage area consists mainly of boreal forest; supplying the Bay with organic matter (Kupariinen et al. 1996). Along the coast metal, chemical and wood processing industries are located; discharging acidifying substances, heavy metals, nutrients and persistent organic compounds (Laine, Kronholm 2005).

The Bay has a mean depth of 40 m and is poor in both nutrients and species (HELCOM 2010a; Håkansson et al. 1996). Freshwater inflow from rivers adds up to approx. 115 km³/yr., which is slightly higher than the annual run-off (Håkansson et al. 1996; Laine, Kronholm 2015). Water run-off reaches its maximum during May and June and remains relatively...
constant the rest of the year. Annual precipitation equals almost evaporation (Håkansson et al. 1996).

**Water chemistry and nutrient load**

The Bothnian Bay contains brackish water with a salinity which decreases towards the north and lies between 2 and 4 psu (Håkansson et al. 1996; Kuparinen et al. 1996; Foberg 1994; Nilsson 2016). Phosphate is the limiting factor in the Bay’s nutrient-poor water; even though inputs of nitrogen and phosphor into the Baltic Sea have been increasing significantly during the last century (Wulff et al. 1996; Laine, Kronholm 2005). Phosphor concentrations remain low all year round; showing little seasonal variation (Wulff et al. 2006). Nitrate levels however are comparatively high in the Bay. Nutrient levels in its surface water reach their peak in March as a consequence of the spring melting (Jonsson et al. 1996; Wulff et al. 1996). Bothnian Bay is subject to an increase in organic matter; with ⅓ of all organic matter coming from river discharge (Wulff et al. 1996; Kuparinen et al. 1996). However, eutrophication effects are still small, which stands out compared to other areas in the Baltic (HELCOM 2010a; Wulff et al. 1996; Laamanen 2013). Nevertheless, eutrophication is slightly more visible along the Finnish compared to the Swedish coast; almost certainly a result of a more extensive forestry in Finland (Furman et al. 2016; Foberg 1994).

**Circulation patterns and wave heights**

Summers in Bothnian Bay are accompanied by a thermocline, which is especially pronounced in areas with depths greater than 20 m. In the more shallow regions, the thermocline is temporary even during summer (Kronholm et al. 2005). In autumn, the thermocline towards the Bothnian Sea disappears and the surface water in Bothnian Bay is completely wind-mixed (Wulff et al. 1996). Lacking a halocline, oxygen levels remain good and almost constant at all depths (Furman et al. 2016).

The surface layer accounts for the majority of the north–south water transport along the coasts. The water circulation has a tendency to be cyclonic and intermittent as it is strongly wind dependent. Additionally, there is a slow estuarine circulation in the Gulf of Bothnia which tends to be counter-clockwise in its rotation pattern; with the dominating currents going north-east and south-west (see Figure 2. Long term mean surface circulation in Bothnian Bay. Source: Furman et al. (2016))
The velocity of the northward flow in the Bay resembles that of many ocean currents (Håkansson et al. 1996; Lumpkin, Johnson 2013). Open sea wave heights have increased in the past decades; with maximum heights increasing from 3.1 m in the 1980s to 4.4 m in 2014 (Pettersson et al. 2015).

**Ice cover**

Every winter the Bay is covered with ice of 0.8 – 1 m thickness, lasting for four to seven months. In strong winters, ice build-up starts in October; mild winters can keep the Bay ice-free until the end of December (HELCOM 2010a; Håkansson et al. 1996; Foberg 1994). During winter in 2014/15, Bothnian Bay remained partially ice-free for the first time since the beginning of recording. Climate models foretell that this extreme event will be a common one in 50 years (Uotila et al. 2015).

### 3.1.2 Contaminants in Bothnian Bay

The oligotrophic character of the Bay increases its susceptibility for toxic substances. Moreover, the regional climate could favour the accumulation of persistent contaminants (HELCOM 2010a; Jonsson et al. 1996). Waste disposal from industries, rural and urban settlements as well as river borne nutrients, airborne radionuclides from Chernobyl and nuclear weapons test and other materials reach Bothnian Bay (Håkansson et al. 1996; Zalewska, Saniewski 2011). Pollutants and dissolved substances can be distributed inhomogeneously in the water body (Monte et al. 2008).

In Bothnian Bay the accumulated amount of contaminants in sediments is estimated to 500 tonnes. The ongoing land uplift in the region could cause erosion of the contaminated sediments, making them bioavailable again (Leivuori, Niemistö 1995; Jonsson et al. 1996).

**Radionuclides**

Bothnian Bay has received a measurable amount of radionuclides from the Chernobyl accident; with Finnish ecosystems facing slightly higher amounts than Swedish ones (HELCOM 2009b). Pre-Chernobyl levels of Cs lay around 15 Bq/m³ in surface sea water. Today, Bothnian Bay faces levels of 40 Bq/m³. In sediments, highest levels of radionuclides were discovered in the northernmost parts of the Baltic Sea. The remobilization of Cs from bottom sediments is a likely scenario for the future (HELCOM 2009b). Also strontium and tritium concentrations are several times higher in Bothnian Bay water today than before the
catastrophe (HELCOM 2009b). In marine round fish like herring, mean concentrations of $^{137}\text{Cs}$ varied between 0.7 and 7 Bq/kg w.w. (wet weight) in the Baltic Sea in 2010. Freshwater fish like pike reached levels of 15 Bq/kg w.w. Even for $^{90}\text{Sr}$, highest levels were found in herring with 0.056 Bq/kg w.w. and in pike with 0.018 Bq/kg w.w. (Iosjpe et al. 2014).

**Trace metals and others**

Concerning trace metals, the Finnish side of Bothnian Bay is classified as one of the cleanest in the Baltic Sea area (HELCOM 2010b). Nonetheless, concentrations can vary significantly in the same area (Lindqvist et al. 1991). Concentrations of copper, zinc and lead are lower in the northern than in the southern parts of the Baltic Sea (Jonsson et al. 1996). Bothnian Bay faces high concentrations of mercury and cadmium. Arsenic levels are classified as unacceptably high and degrade only slowly (Lindqvist et al. 1991; Vallius 2014; Jonsson et al. 1996). Several samples from the Bay display even high levels of chlorinated biphenyles and high amounts of organic chlorine and organic halogens which have accumulated in sediment and biota (HELCOM 2010b; Laine, Kronholm 2005).

**3.1.3 Ecology and species composition**

Compared to the Bothnian Sea, primary production in Bothnian Bay is significantly lower (Laine, Kronholm 2005; Anderson 1996). Mainly, this is an effect of the brackish water environment, leading to a lower species richness than in purely marine or freshwater ecosystems. Species richness increases towards the coast (Laine, Kronholm 2005). Small changes in that environment can have significant effects on the ecosystem (HELCOM 2010a). Classification of Bothnian Bay’s ecosystem results in three different biotopes; the free water (pelagic zone), the shallow water and the deep seafloor (Anderson et al. 1996; Kronholm et al. 2005).

**Algae, bacteria and insects**

Phytoplankton and zooplankton form the basis of marine food chains. Consequently, any impacts and changes in those organisms will affect even higher trophic levels (Apte 2012).

A key factor for the Bay’s low primary production is the limited availability of nutrients; mainly phosphate.

<table>
<thead>
<tr>
<th>Copepod</th>
<th>Eurytemora affinis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Limnocalanus macrurus</td>
</tr>
<tr>
<td></td>
<td>Acartia sp.</td>
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<td></td>
<td>Cyclopoidea spp.</td>
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</tbody>
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<tr>
<th>Cladocera</th>
<th>Osminia longispina maritima</th>
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<tr>
<td></td>
<td>Daphnia cristata</td>
</tr>
<tr>
<td></td>
<td>Evadne nordmannii</td>
</tr>
<tr>
<td></td>
<td>Pleopsis polyphemosides</td>
</tr>
<tr>
<td></td>
<td>Ceropagis pengoi</td>
</tr>
</tbody>
</table>

| Rotifer          | Synchaeta spp.              |
|------------------| Keratella coehlearis        |
|                  | recurvispina                |
|                  | Keratella quadrata          |
|                  | Asplancha priodonta        |

Table 1. Common zooplankton in Bothnian Bay. Modified after Kronholm et al. (2005)
Another one is the amount of humus discharged by rivers which strongly influences the availability of light (Kronholm et al. 2005). The availability of light is especially pronounced in coastal areas and is further reduced due to the long period with ice cover (Kronholm et al. 2005; Laine, Kronholm 2005).

The low phytoplankton biomass limits the amount of zooplankton. However, the humus discharged into the Bay allows for a higher productivity than normally the case. Zooplankton species composition (see table 1) is dependent on water temperature and strength of the thermocline. Larger parts of the year, species of Copepods are dominant (Kronholm et al. 2005).

Bacteria have a remarkably high significance in the food chain of Bothninan Bay due to the high freshwater influx. Blue-green algae however are rare due to the limited amount of available phosphor (Furman et al. 2006; Kronholm et al. 2005). Insects are dominated by Caddiflies (Trichoptera), Mayflies (Ephemeropter) and Chironomidae larvae (Kronholm et al. 2005). Smaller species groups are not accounted for here.

**Marine-glacial relicts**

Saduria entomon and Monoporeia affinis, as well as Four-horned sculpin and vendace are so called marine-glacial relicts. Saduria and Monoporeia are an important part of the food web as they are eaten by many predators such as burbot and whitefish (Guban et al. 2015; Kronholm et al. 2005). Monoporeia feeds on phytoplankton from the upper layer of sediment (Kronholm et al 2005). Monoporeia affinis genetics changed and showed a lower variation at contaminated sites. Saduria is mainly feeding on Monoporeia but even on detritus (Guban et al. 2015).

**Benthic community**

Benthic macrofauna is extremely low in species; especially at the deep bottoms. Until recently it was exclusively dominated by Monoporeia and Saduria. Lately however, polychaete spread northwards and are expected to increase in number in the future (Kronholm et al. 2005; Laine, Kronholm 2005).
The Bay’s meiofauna is slightly richer in species, with the most common groups being Nematodes, Ringed worms, bottom living Copepods and Ostracods (Kronholm et al. 2005). The Benthic community can be divided into species living on hard and those living on soft bottoms (see table 2 and 3).

**Fish**

In fish abundance, there is no significant difference between Bothnian Bay and Bothnian Sea (Kronholm et al. 2005). However, the fish community in Bothnian Bay has been relatively stable and is characterized by an abundance of freshwater species (see table 4) (Laine, Kronholm 2005; Olsson et al. 2013; HELCOM 2013). The overall most abundant species are vendace and Baltic herring, both feeding on plankton (Kronholm et al. 2005; Foberg 1994).

The free water generally contains fewer species than coastal and shallow areas. Baltic herring, Salmonidae, smelt and Three-spined stickleback are among those represented in both (Kronholm et al. 2005).

Vendace feed on zooplankton and spawn in shallow areas in autumn; mainly at the Swedish side of the Bay. Almost all vendace fishing in the Baltic Sea is done in Bothnian Bay. Vendace is prey for e.g. burbot.

Baltic herring spawn in shallow areas; avoiding soft bottoms and placing the spawn on hard bottoms or on algae. In Bothnian Bay, the mating period begins in June. Its main food consists of animal plankton and Monoporeia. Baltic herring is prey for e.g. salmon.

Two types of whitefish are common in Bothnian Bay – the sea breeding and the river breeding whitefish. The sea breeding type is more common in the northern parts of the Bay and requires sandy bottoms; found mainly along the Finnish coast. Whitefish mainly feed on animal plankton and Monoporeia. Burbot is the only species from the cod family surviving in fresh- and brackish water environments. They feed on e.g. Monoporeia, Saduria and other Amphipods as well as on fish like vendace, smelt and Three-spined stickleback. Smelt is even prey for perch and Northern pike which live in shallow, coastal areas (Kronholm et al. 2005).

<table>
<thead>
<tr>
<th>Freshwater species</th>
<th>Migrating species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern pike</td>
<td>European river lamprey</td>
</tr>
<tr>
<td>Smelt</td>
<td>Whitefish</td>
</tr>
<tr>
<td>Vendace</td>
<td>Salmon</td>
</tr>
<tr>
<td>Bream</td>
<td>Brown trout</td>
</tr>
<tr>
<td>Roach</td>
<td>Marine species</td>
</tr>
<tr>
<td>Ide</td>
<td>Baltic herring</td>
</tr>
<tr>
<td>Dace</td>
<td>Three-spined stickelback</td>
</tr>
<tr>
<td>Bleak</td>
<td>Lumpsucker</td>
</tr>
<tr>
<td>Burbot</td>
<td>Sand goby</td>
</tr>
<tr>
<td>Nine-spined stickelback</td>
<td>Invasive species</td>
</tr>
<tr>
<td>Perch</td>
<td>Rainbow trout</td>
</tr>
<tr>
<td>Ruffe</td>
<td>Lake trout</td>
</tr>
<tr>
<td>(Alpine) Bullhead</td>
<td></td>
</tr>
<tr>
<td>Four-horned sculpin</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Most common fish species in Bothnian Bay. Whitefish includes both river and sea breeding. Modified after Kronholm et al. (2005)
Seals

Two types of seals inhabit Bothnian Bay – the Ringed seal (*Phoca hispida botnica*) and the Grey seal (*Halichoerus grypus*). Seals are dependent on the winter ice cover for their survival (Foberg 1994). Ringed seals have their main breeding area in Bothnian Bay and give birth to their offspring on fast ice. In Bothnian Bay, there are a unique subpopulation and the only subpopulation of ringed seals in the Baltic with a positive rate of increase (HELCOM 2015). Ringed seals feed on fish, mainly Baltic herring, Cottidae but even on Saduria and other Crustaceans. Ringed seals occur often in coastal areas, bays and sometimes even in river mouths (Kronholm et al. 2005). Ringed seals have been severely affected by sterility due to polychlorinated biphenyls (PCB) (HELCOM 2015).

Grey seals occur mostly further away from the coast and further south than Ringed seals; being more dependent on the open water during winter. Grey seals feed on Baltic herring, salmon, cod and flounders but do not reproduce in Bothnian Bay (Kronholm et al. 2005).

3.2 Hanhikivi

3.2.1 Site description

The headland of Hanhikivi is situated in the municipality of Pyhääjoki in Finland; approx. 10 km from Pyhääjoki city (see fig. 1). Within a radius of 20 km from the planned NPP, 10 – 15 000 inhabitants are living (Fennovoima 2008, 2014). There are no bigger industries in the municipality. Six kilometres west of Hanhikivi, Pyhääjoki River flows into the Bothninan Bay (Fennovoima 2014, 2015). Hanhikivi is mostly covered by forest vegetation and a few holiday houses (Pyhääjoki 2016).

The sea off the Hanhikivi coast is open, shallow and rocky (Fennovoima 2014, 2015). The sea water temperature around Pyhääjoki is highest during July and August with a max temperature of 18.7 °C in 2009. Average salt content lies at 3 ‰, decreasing to 2 ‰ during the spring flood. Oxygen-saturation is 78 – 105 % at all depths (Fennovoima 2014).

The terrain on the headland is mainly flat and straight; with the highest point at 5 m.a.s.l. Hanhikivi headland and its surroundings are mainly in their natural state (Fennovoima 2008). The western shore of the headland is characterized by bare sandy ground; followed by a zone with bushes and trees (Fennovoima 2008). The closest classified groundwater area is situated
approx. 10 km away. Geologically, Hanhikivi headland is a slate area (Fennovoima 2014).

3.2.1 Project description and the VVER-1200 (AES 2006)

Fennovoima AB plans to build Hanhikivi 1, a 1200 MW NPP on the headland of Hanhikivi in Finland. The power plant is a Russian generation III+ VVER-1200 (AES-2006) reactor; with a design closest to pressurized water reactors (PWR) (ROSATOM 2013, Fennovoima AB 2014; Dragunov et al. 2007). Currently, there is no plant of that type in operation. However, it is under construction in Novovoronezh and Leningrad and in planning at several other locations (Fennovoima 2014).

In PWR, high pressurized water from the reactor is lead to the steam generator where it evaporates: The steam drives the electrical generator and the turbines. The VVER-1200 will use Bothnian Bay as a water source (Fennovoima 2014; 2015).

The cooling water intake will be situated on the western side of Hanhikivi (see fig. 3), at a depth between 4 – 11 m in the harbour basin. The cooling water intake will be protected by a 15 – 17 m broad construction of concrete and a grid separating coarse substances from the water. The cooling water intake at the planned nuclear plant in Pyhäjoki has a grid with 10 cm intervals (Fennovoima 2014).

From the west, an 8 m deep and 80 m wide water-way will be built. At the northern coast of the headland, the cooling water discharge will be placed (see fig. 3). The discharge channel will be 3 m wide and 80 m deep (Fennovoima 2014).

Since August 2015, access to Hanhikivi has been restricted and a fence has been put up around the site. In November 2015 the site was added to the Ministry of the Interior’s decree on restrictions of movement and presence. In January 2016, the first representatives of labour
forces began their work at the Hanhikivi site. In the writing hour, Fennovoima is looking for thousands of new employees. Furthermore, contracts with dredging companies have been signed (Fennovoima 2016).

3.3 Impact of nuclear power plants on aquatic environments

Nuclear power plants emit substances that can harm the environment (Chatzimouratidis, Pilavachi 2007). During normal operation, the concentration of radionuclides emitted is smaller than the average natural background radiation. Normally therefore, the NPP contribution of radionuclides to the radioactive level in the environment is low (Zhang et al. 2014).

Comparing the input from Chernobyl of 5000 TBq into the Baltic Sea, NPP in the area are responsible for 2.4 TBq (Iosjpe et al. 2014). Measuring radioactivity in aquatic environments requires knowledge of local tides and currents. Solely sampling surface water for instance will underestimate the radioactive load when not taken immediately after the discharge. Subsurface radioactivity levels will otherwise be higher as radionuclides also are transported vertically (Batlle 2001).

Besides emitting radionuclides, NPP cause stress to the environment through the usage and discharge of large amounts of cooling water. A nuclear plant with the size of 1200 MW uses around 40 – 45 m³/s for cooling the condensers. (Fennovoima 2014).

3.3.1 Construction phase

General effects of construction works at Hanhikivi

During construction, a lot of traffic, stone crushing and other ground work will be practised. Almost all vegetation cover will be removed from the headland changing the influx of nutrients/organic matter to the Bay. Furthermore, there will be explosions under water which will discharge nitrogen. Silt that is transported from the basins on land or blown up and later deposited again can contain a certain amount of solid substances. The construction work will create considerable noise, above ground and under water (Fennovoima 2014).

Dredging

Dredging causes various impacts which are illustrated in fig 4. Impacts on the aquatic environment are evident during the three dredging stages – the extraction, the transport and the disposal of the material. A loss of bottom-habitation of 40 hectares is expected as a
consequence of the construction in the water. These areas are used for reproduction of both whitefish and Baltic herring; as well as for schools of vendace and Baltic herring. The explosion from the construction work will cause a shock-wave killing and injuring fauna in its surroundings (Fennovoima 2014). Among others these impacts include spreading of contaminants from sediment to water, which is followed by the exposure of fish and benthic organisms to contamination. Furthermore, the changing of the sea bottom surface and the formation of temporary dredging plumes (Manap, Voulvoulis 2014). Grayling mates in spring just south of the headland (Fennovoima 2014).

Around Hanhikivi the bottom material is mainly coarse, consisting of sand and gravel; with a sedimentation rate of ca. 1 cm/s. The dredging of the water-way and the harbour takes place in areas with finer fraction sizes. The area around the water way and harbour will therefore experience a stronger clouding as sedimentation of fine material is slower. Every 10th year, new dredging will be necessary for maintenance of the water-ways (Fennovoima 2014).

**Landfill**

Landfill areas will be situated approximately 9.5 km west from the Hanhikivi headland, in the open sea. The landfill is expected to have an area of ca. 190 hectares. At the landfill site, the

![Flow chart summarizing effects of construction work at Hanhikivi on Bothnian Bay fauna.](image)

*Figure 4. Flow chart summarizing effects of construction work at Hanhikivi on Bothnian Bay fauna.*
bottom-living fauna will die under the deposited material. Both salmon and migrating whitefish pass the landfill area during their migration (Fennovoima 2014).

3.3.2 Operational phase

Discharge patterns of nuclear power plants during normal operation are similar among reactor types and include radionuclides (Lünig et al. 2009; Bird et al. 1997). Impact of NPP on aquatic environments can also be the effect of atmospheric fallout (Jha et al. 2012). The evaluation of toxic and non-toxic effects of radionuclides should be performed under conditions of “chronic radioactive exposure”. In reality however, they are realized with only short exposure (Kudryasheva, Rozhko 2015).

Radionuclides in general

The natural cleaning process of radionuclides in aquatic environments includes natural decay, dilution by precipitation and by freshwater inflow from rivers. Naturally, that depends on the oceanographic characteristics of the water body concerned. In the Baltic Sea the dilution of radionuclides from the Chernobyl accident is very slow (see also fig. 5). Radionuclides can be removed from the surface water through the uptake by planktonic algae, sink to deeper water and sediments (Fowler 2010). Caesium and strontium are of special concern among artificial radionuclides as their chemical characteristics are similar to potassium and calcium respectively. Consequently, they are easily transported in the food chain (Iosjpe et al. 2014).

The Chernobyl accident is the single most important source (83 %) of artificial radionuclides in the Baltic Sea. Cs fallout from the Fukushima accident is valued insignificant considering present dosages as a consequence of Chernobyl (HELCOM 2013b). In total, the input from Chernobyl adds up to 4700 TBq. $^{137,134}$Cs are dominating among artificial radionuclides in the Baltic Sea. Pre-Chernobyl $^{137}$Cs levels are expected to be reached by 2020. In Bothnian Bay, pre-Chernobyl levels in surface water are estimated to 15 Bq/m$^3$ (HELCOM 2013b). During normal NPP operation, tritium is the radionuclide discharged most (Iosjpe et al. 2014; Lünig et al. 2009). Table 4 lists some of the NPP with radionuclide discharges into the Baltic Sea. All Swedish and Finnish NPP emit several artificial radionuclides; besides tritium, even cobalt, caesium, manganese and others (HELCOM 2009b). Increased levels of those radionuclides are found in up to 5 km distance from the plants.
Contamination decreases with distance. Radionuclide concentrations in plankton or benthic algae were highest during growing season. Low concentrations however are unlikely to cause serious effects on the environment (Zakaria et al. 2008).

Compared to terrestrial environments, aquatic environments display on average higher levels of radionuclides. Besides tritium, $^{60}$Co and $^{137}$Cs are detected most frequently in sediments and water. Highest amounts of both were detected in sediments (Wallberg, Moberg 2002; Janovics et al. 2013; Mazeika et al. 2015). Different wind directions can cause sudden local concentration increase in the surface water and changes in sediments can lead to renewed spreading of radionuclides to the surface waters (Styro et al. 2000).

<table>
<thead>
<tr>
<th>Name, location and reactor type</th>
<th>Main radionuclides discharged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loviisa, Finland, 2 PWR</td>
<td>$^3$H, $^{60}$Co, $^{137}$Cs, $^{110m}$Ag, $^{124}$Sb, $^{58}$Co, $^{54}$Mn</td>
</tr>
<tr>
<td>Olkiluoto, Finland, 2 BWR</td>
<td>$^3$H, $^{60}$Co, $^{137}$Cs, $^{51}$Cr, $^{134}$Cs, $^{58}$Co, $^{54}$Mn</td>
</tr>
<tr>
<td>Barsebäck, Sweden, 2 BWR (shut down)</td>
<td>$^3$H, $^{60}$Co, $^{137}$Cs, $^{51}$Cr, $^{58}$Co, $^{54}$Mn</td>
</tr>
<tr>
<td>Forsmark, Sweden 3 BWR</td>
<td>$^3$H, $^{60}$Co, $^{137}$Cs, $^{51}$Cr, $^{58}$Co, $^{54}$Mn, $^{65}$Zn, $^{124}$Sb, $^{110m}$Ag</td>
</tr>
<tr>
<td>Oskarshamn, Sweden, 3 BWR</td>
<td>$^3$H, $^{60}$Co, $^{58}$Co, $^{137}$Cs, $^{51}$Cr, $^{54}$Mn, $^{95}$Nb, $^{125}$Sb</td>
</tr>
<tr>
<td>Ringhals, Sweden 3 PWR, 1 BWR</td>
<td>$^3$H, $^{60}$Co, $^{58}$Co, $^{137}$Cs, $^{51}$Cr, $^{54}$Mn, $^{95}$Nb, $^{125}$Sb</td>
</tr>
</tbody>
</table>

Table 5. Radionuclide discharges from NPP in the Baltic Sea drainage area. Modified after HELCOM (2009b)

**Caesium**

Caesium-134, 137 is one of the most serious among radioactive fission products because of its slow decay process (half-life 30 years) and high bioavailability. Compared to other marine environments in the world, the Baltic Sea faces the highest levels of $^{137}$Cs in surface waters (see also fig. 5; HELCOM 2013b). However, both caesium and strontium levels in Bothnian Bay are significantly higher in bottom than in surface waters (Iosjpe et al. 2014).

$^{137}$Cs can lead to biomagnification; especially in areas with good growth conditions (Hongve,
Shortly after the Chernobyl accident, concentrations of $^{137}\text{Cs}$ increased rapidly in Baltic green algae and shortly after in bottom-living animals. In fish and especially in larger predators, $^{137}\text{Cs}$ concentrations increase and decrease more slowly, reaching their maximum levels with some delay compared to the seawater (Sandström 1990; HELCOM 2009b; see fig 5 and 6). In fauna, caesium accumulates primarily in muscle tissue (Arai 2014; Hongve, et al. 2000). However, concentrations of $^{137}\text{Cs}$ in marine species display huge differences according to spatial distribution, habitat and taxa. In pelagic fish and invertebrates, concentrations declined more rapidly than in demersal fish; indicating a continuous uptake of $^{137}\text{Cs}$ in the benthic food web (Wada et al. 2013). In surface water, $^{137}\text{Cs}$ concentrations can change rapidly due to different hydrological events (Iosjpe et al. 2014).

**Tritium**

Tritium is a radionuclide of hydrogen with an approximated half-life of 12 years (Turner et al. 2009; Le Guen 2009). Tritium is produced by a variety of NPP processes and emitted mainly in the form of $^3\text{H}_2\text{O}$ (tritiated water, HTO). Light-water reactors emit approximately 222 kBq of tritium per year (Hanslik 2008; McCubbin et al. 2001; Lünig et al. 2009; Lindén et al. 1974). $^3\text{H}$ is taken up quickly by living matter (Lindén et al. 1974). Demersal fish, benthic organisms, molluscs and sediments display significantly increased levels in the vicinity of NPP (McCubbin et al. 2001; Janovics et al. 2013). Tritium is taken up rapidly by the tissue-free water and more slowly by organic matter in organisms’ cells. Generally, exposure to tritiated water leads to lower levels of $^3\text{H}$ in organisms than the consumption of
tritiated food (McCubbin et al. 2001; Turner et al. 2009). Even though tritium is a beta-emitter, it can be more harmful for aquatic invertebrates than gamma-emitters. Laboratory experiments have shown that exposure to HTO below 500 µGy/h is capable of inducing genetic damage in adult bivalves (Jha et al. 2005). \(^3\)H has the ability to increase by bioaccumulation (McCubbin et al. 2001; Janovics et al. 2013).

**Plutonium, carbon and radioactive waste water**

Plutonium (\(^{210}\)Po) isotopes are among the more toxic radionuclides (Skwarzec et al. 2000) and \(^{210}\)Po levels are highest in organisms at the base of the food chain; e.g. in zooplankton. Plutonium is transported up the food chain; which can result in biomagnification at higher trophic levels (Fowler 2010).

Carbon-14 (\(^{14}\)C) is a radionuclide with a half-life of 5730 years, which is emitted during normal operation of all types of NPP (Aquilonius, Hallberg 2014; Dias et al. 2009). After mixing in the atmosphere it can be incorporated by plants via photosynthesis. Atmospheric background values today are estimated to 241 Bq/kg C (44 MBq/m³; Dias et al. 2009). In PWR, \(^{14}\)C is produced mainly in the cooling system and is released as airborne effluents in oxidised and reduced form (Stenström et al. 1996; Yim, Caron 2005; Aquilonius, Hallberg 2014). Samples taken in the vicinity of NPP in both Europe and South America revealed highest measured values in flora about 60 Bq/kg C above natural background radiation (Dias et al. 2009).

After dispersion, the majority of radioactive wastewater will accumulate at the seabed. In the long-run, most of the accumulated radionuclides will be remobilized and be available for biota once again. Shallow parts of the ocean contain in general higher radioactive contamination (Wada et al. 2013). Release of low-level radioactive waste resulted in elevated levels of Cs and Po in Mediterranean seawater, sediment and green algae. \(^{137}\)Cs values in seawater reached 11.6 Bq/m³ compared to the average of 5.6 Bq/m³ and \(^{239, 240}\)Pu was 16.9 Bq/m³ and \(^{238}\)Pu 2.5 Bq/m³ (average 11.2 and 0.6 Bq/m³ respectively) (Sanchez-Cabeza, Molero 1999). Discharges into the river basins of Vltava and Labe displayed mainly significantly elevated concentrations of \(^3\)H (Hanslik et al. 2008).

**Impacts of radionuclides on fauna**

Operation of nuclear power plants can locally result in substantial changes in the ecological environment (Wang 2011; Zhou et al. 2015). Heated NPP effluents act as environmental
stress in seaweed community structures and largely affect the succession and development of benthic marine algal communities (Choi 2008; Kim et al. 2007). The majority of radionuclides in fauna are a result of absorption by ingestion. The uptake from water i.e. by gills plays a less important role (Carvalho 2011). Moreover, concentrations of radionuclides differ in different phylogenetic groups and between different tissues in one species (Fowler 2010; Skwarzec et al. 2000). The behaviour of radionuclides can also differ depending on the environment. $^{90}$Sr concentrations decrease more slowly in freshwater than in marine environments (Mirzoyeva et al. 2013).

Generally, benthic fauna tends to accumulate more radionuclides than pelagic organisms; mainly due to their more stationary behaviour and higher exposure to contaminated sediments (Wang 2011). Consequently, pelagic fish are in general influenced to a lesser extend from the NPP discharges as a result of their wandering behaviour (McCubbin et al. 2001; Janovics et al. 2013).

At Forsmark NPP radionuclide concentrations in fish are small, even close to the plant in Biotestsjön. None of the radionuclide concentrations exceeded 100 Bq/kg dry weight; indicating that the yearly emissions adds up to just 0.1 % of the natural background radiation (Sandström 1990). However in seals from the Baltic we have levels of about 120-140 Bq/kg wet weight (Ciesielski 2015; Carroll et al. 2002).

Figure 7. Flow chart summarizing impacts of Hanhikivi 1 operation on Bothnian Bay fauna.
3.3.3 Cooling water

Discharge and intake of cooling water create unique micro-environments (Kim et al. 2007). Temperature stress on the aquatic organisms can be magnified by their exposure to other environmental stresses. Heated discharges into water bodies increase biological activity and decrease at the same time the amount of dissolved oxygen (Zargar, Gosh 2006).

**Cooling water intake**

Effects of the cooling water intake on fish include them being caught in the inflow and dying. At the Forsmark NPP the cooling water intake led to the death of several million fish, mainly spawn of Baltic herring and Three-spined stickleback (Sandström 1990). At the two plants in Olkiluoto, 1.5 – 7 tonnes of fish die each year in the water intake (Teollisuuden Voima Oy 2006). The surge of the cooling water intake changes flow patterns in the region, resulting in impoverishment of the sea bottom and erosion of sediments. However, the effect on bottom-living fauna seems limited. Many fish are enticed by the cooling water intake (Sandström 1990).

**Cooling water discharge**

Discharged cooling water from a nuclear power plant is 10 – 12°C warmer than it was at the intake (Fennovoima 2014). In very well-mixed environments, the thermal plume of the cooling water changes temperatures around the discharge point only about 3 – 5°C. Such minor temperature changes have limited effects on benthic flora and fauna (Apte 2012). Normally however, temperature changes are greater. In Bothnian Bay, temperature increases of more than 9 °C are expected to affect an area of 0.12 km². An average increase of 2 °C could impact an area of 2 – 3 km (Fennovoima 2014).

Furthermore, through the cooling water outlet, discharges of neutron activation products (tritium, carbon-14, cobalt etc.) are common (Zakaria et al. 2008). Overall, the increased temperature around the discharge increases the abundance in fish and bottom-living fauna (Sandström 1990). The warm water discharge leads to a decrease in zooplankton motility and abundance as well as to a decrease in the abundance of nematodes. Species abundance in general however, was highest close to the water outlet (Sundri, Gomoiu 2014; Zargar, Gosh 2006; Kim et al. 2013). Temperatures higher than optimal (e.g. discharge in addition to warm summers) can lead to a strong negative effect on growth in all species. The effect of cooler
summers however can be counteracted by the water discharge (Sandström 1990).

*Effects on fish*

Water temperatures higher than normal can lead to a change in growth patterns, gender processes and the ability to spawn; as well as to changes in the accessibility of food, which affects the whole stock. Full-grown fish have a lower temperature optimum than young ones and can therefore be stricken more easily when living close to the cooling water discharge. Pike and ruffe are clear examples facing impeding growth. Perch on the other hand benefit from higher temperatures than normal; resulting in a slight increase in abundance and larger individuals at all age-groups (Sandström 1990; Sundri, Gomoiu 2014). Warmer winter temperatures seem to have negative effects on the reproductive organs of among others roach; resulting in fewer spawn and a minimized stock (Kim et al. 2013). In Biotestsjön at the Forsmark NPP, cold water species disappeared totally, leading to a domination of warm water species after the first years of operation. Fourhorn sculpin, whitefish, burbot and Baltic herring disappeared and were replaced by roach, bleak and perch. Baltic herring reacted most strongly on the cooling water discharges, as it was found to be a stationary species in that part of the Baltic. During the first year of operation, 2.4 million and in the following year 5.5 million Baltic herring died. Less than 5 km away from the discharge point, the most apparent changes are expected in stationary, which is mainly freshwater, species (Zargar, Gosh 2006; Sandström 1990).

*Effects on bottom-living organisms*

Bottom-living organisms are affected by the cooling water in two ways. Firstly, they face changed conditions for reproduction, growth and survival. Secondly, the increased flow from the discharge changes sediments and the availability of nutrients which can result in a changed species composition. With the inflow of cooling water, circulation patterns change and most likely, the warmer water will increase the total production of bottom-living organisms. All these effects decrease with increasing distance from the discharge point and are mainly local (Sandström 1990; Sundri, Gomoiu 2014). The impact was highest in Cladocera; leading to an accumulated loss of crustacean plankton of more than 100 tonnes per year in the Baltic Sea as a result of the Forsmark NPP (Kim et al. 2013; Sandström 1990).
Parasites and diseases

Concerning diseases and parasites, most species show no significantly higher infection risk. However, fish being attracted by the discharge plume have a higher risk of getting diseases and parasites that benefit from the warmer water temperatures. That is for instance skin-parasites, fish leech and parasite crustaceans which can enhance secondary inflamations in fish. Trout is one species that likes to be close to the discharge (Sandström 1990).

3.3.3 Bioaccumulation of radionuclides

Several aquatic fauna are capable of accumulating radionuclides (Sanchez-Cabeza, Molero 1999; Skwarzec et al. 2000; Lünig et al. 2009). Bioaccumulation is determined by different factors (Zalewska, Saniewski 2011). Filter feeding plays an important role in bioaccumulation of artificial radionuclides. Bioaccumulation of those radionuclides was found to occur in demersal fish, bivalves and sponges from Antarctica. Atmospheric fallout of artificial radionuclides can lead to accumulation in benthic fauna (Nonnis Marzano et al. 2000). Both temperature and pH play a significant role in the bioaccumulation of radionuclides. Amounts of $^{134}$Cs increased in cuttlefish egg facing an environment with decreasing pH and rising temperatures. In the future therefore, ocean acidification (decreasing pH) and temperature rises could enhance the accumulation of radionuclides (Lacoue-Labarthe et al. 2011). Marine mammals also biomagnify radionuclides such as Cs-137 (Ciesielski et al. 2004).

3.4 Environmental Impact Assessment made by Fennovoima

3.4.1 Constructional phase

During the construction works, Fennovoima expects clouding in the dredging area, with temporary effects on sea-mating grayling. The dredging is not expected to cause a release of nutrients or harmful substances to the water. Mating of whitefish and Baltic herring will be severely impacted during the three years of construction. Noise and clouding can affect the route of salmon and migrating whitefish. Bottom-fauna in the dredging area will disappear but is expected to be fully restored after a few years. The total landfill has an area of ca. 190 hectares. Ninety percent of the material is expected to sediment one day after deposition. Bottom-living fauna will die under the deposited material; but will be restored after a few years. NPP construction also includes under water explosions discharging nitrogen which could cause temporary eutrophication. The explosion is expected...
to have a shock-wave killing all fauna within a 20 m radius. Additionally, it can injure fish and other fauna tenths of meters away. The noise can lead to the escape of species and temporarily to different behavioural patterns (Fennovoima 2014).

3.4.2 Operational phase

Emissions and chemicals

Emissions to the air mainly consist of noble gases, gaseous catalysts, aerosols and halogens. Gaseous radioactive substances are filtered to decrease their radioactivity. Gases with low radioactivity are emitted to the air directly. Dilution in the surrounding air will be fast and only small amounts of radioactivity remain in the close vicinity of the plant. Tritium discharges are expected to be minor and to dilute completely already in the close vicinity of the plant. Hanhikivi 1 is expected to use 200 tonnes of chemicals every year. An amount of 1000 – 2000 tonnes fuel oil is stored at the plant site (Fennovoima 2014).

Impact on fauna

No larger impact on the regions’ fish stock is expected. Fish are expected to move and avoid the warm water around the cooling discharge. However, the discharge will favour spring-mating species whilst autumn-mating species will face more difficult living conditions. Warmer water could lead to invasion of North American peacock worm, Zebra and Conrad’s false mussel. The project is expected to not interfere with the seal stock, the seals’ habitat and/or mating sites. No mating seals have been observed in the region impacted by the cooling water (Fennovoima 2014).

Waste water, cooling water discharge and ice cover

Waste water is cleaned and radioactivity removed before discharged into the Bay together with the cooling water. The combined effect of cooling and waste water includes an increase in phosphorous in the area with less than 1 % and in nitrogen with less than 2 %. Except for the temperature, the cooling water remains unaffected while running through the NPP. Effects of the discharge are obvious only in the uppermost layer (0-1 m) and decrease with increasing depth and distance from the discharge point. Temperature increases of more than 9°C are expected to affect an area of 0.12 km². An average increase of 2°C could impact an area of 2 – 3 km. During summer, the cooling water could stimulate algae growth. The area that is expected to be ice-free during winter is estimated to 2.4 – 4.5 km².
4 DISCUSSION

4.1 Impacts of a NPP to Bothnian Bay fauna

Effects of changes in the Bothnian Bay’s environment are especially difficult to foresee as several conditions make it more vulnerable than marine environments normally are. Consequently, it could be expected that the effects of building and operating a NPP will be greater than at other sites located at the coast and even in other parts of the Baltic Sea. However, there are certain indications of impacts and changes that are more certain than others.

Naturally, Bothnian Bay will be exposed to artificial radionuclides. Even though NPP during are expected to emit only minor amounts during normal operation, there are neither long-term studies on the effects of those; nor are there exact values of harmful/harmless levels. Moreover, the risk of leakage from radioactive waste, chemicals and fuel stored at the site has to be taken into consideration. Emissions to air and discharge into the terrestrial environment can eventually reach the sea. As shown under 3.3.3, bioaccumulation of radionuclides occurs in seals and predatory fish. Hence, the potential for bioaccumulation of radionuclides in the vicinity of Hanhikivi 1 is high. Monitoring of radionuclide levels in fish and water might be necessary to avoid consumption of and exposure to elevated radionuclide dosages.

Even though fish are generally affected to a lesser extend from NPP discharges; they too can show stationary behaviour. Consequences will then be severe.

Around the cooling water discharge, species like perch, pike and roach will increase, whereas salmon, smelt and Three-spined stickleback will decrease in number. For salmon and trout, which already face difficult living conditions in Bothnian Bay, further exposure to changes in their habitat could have significant consequences for the whole population. Monoporeia living around Hanhikivi could face genetic changes and it is unclear whether, and if so in what way, this will affect their predators.

Migrating trout will be used as an example for possible impacts of Hanhikivi 1 operation to Bothnian Bay fish. Trout feeds on crustaceans at a young age and later on Baltic herring and
other fish. Consequently, it can be effected directly by a warmer environment, changing its migration route and indirectly through e.g. decreasing availability of food (Baltic herring that is not able to cope with the higher water temperatures). Furthermore, trout could face an elevated risk of diseases as it has shown to be enticed by cooling outlets. As a predator fish, it is exposed to the risk for biomagnification of radionuclides. Without mentioning all Bothnian Bay species in detail, this pattern of direct and indirect effects is applicable for the majority of them. Changes in one species will then affect different trophic levels at the same time.

The higher water temperatures around the cooling water discharge and the input of additional phosphate will increase primary production. In the long-run, this could lead to eutrophication, which in turn has negative consequences for oxygen levels and species survival. Wave heights in the Bay seem to show an increasing trend and could reach 5 – 6 m in the near future; which could cause problems as Hanhikivi headland is very flat. Moreover, there are no indications that Fennovoima prepared for wave heights higher than 3 m. A decreased ice cover can influence the Grey seal’s possibility to successfully give birth to offspring. Especially as seal populations have suffered a lot in past decades, special consideration should be given to ensure their continued existence in the Baltic. As highest predators in Bothnian Bay they face highest contamination levels as a consequence of bioaccumulation. Thus, seals are already and will always be especially vulnerable.

Circulation patterns in Bothnian Bay could enhance the effect of discharged contaminants as they will spread to the rest of the Bay before leaving through the Quark. During summer, a strong thermocline influences the mixing of water and consequently the dilution of contaminants. Similarly, the low water depth in the vicinity of the headland could pronounce local effects of the cooling water. Moreover, dilution from inflowing river water and precipitation play a much smaller role than the dilution by currents. Therefore, even with freshwater inflow being considerable, it cannot counterweigh the limited water exchange. On the other hand, the condensers need ca. 45 m$^3$/sec of cooling water and the Bay has a water volume of 1490 km$^3$. In one year then, the water intake adds up to 1, 42 km$^3$, which is $1/1000^{th}$ of the Bay’s water. Therefore, effects of operational discharges from Hanhikivi 1 will expectedly be mainly local.

Despite the consequences of operation, the building of Hanhikivi 1 leads to impacts that cannot be ignored. Dredging will quite surely release, at least parts of the contaminants
accumulated in sediments. Thus, they are remobilized and once again available for uptake and biomagnification. The landfill and dredging area cover a large region, where all aquatic life will be eliminated. Moreover, most species mate in spring. Hence, construction work during autumn could reduce negative impacts on fish.

In conclusion it has to be said that all impacts and changes mentioned here only give a slight idea about what could happen in case of an accident.

4.2 Environmental Impact Assessment by Fennovoima

At some points, e.g. when referring to the consequences of the cooling water discharge on local fauna, Fennovoima’s EIA lacks scientific reference. The report just states the fact that fish and other fauna will probably disappear for a few years but return after that. Firstly, proof is lacking for that, Fennovoima does not refer to studies that came to similar results. Secondly, the food web in the Bay is vulnerable and the disappearance of species might have significant consequences the balance of that ecosystem. When accounting for the impact of the cooling water discharges on fish especially, there is no specification what is meant by “too warm water” that the fish are supposed to avoid. Summer temperatures are not expected to exceed 26 - 28°C in water. However, this can be lethal for cold water species. Additionally, Fennovoima expects the effects of the discharged cooling water to be only local. However, it can be argued whether an area of 120,000 m² facing a 9 °C rise and an area of 15,000,000 m² subject to an increase in temperature of 1 °C, can be called local.

Despite the high contamination with both radionuclides and other contaminants, information of that is lacking in the description of the current status of Bothnian Bay. Consequently, Fennovoima’s statement that the dredging during construction will not lead to emission of harmful substances from sediments might be false. Furthermore, results will however be different when contamination is added to a clean environment compared to an already contaminated one.

Concerning emissions of radionuclides, the EIA does not mention any other substances than tritium, iodine and $^{14}$C. However, even those are not accounted for in detail. Other radionuclides, such as caesium and strontium are not proclaimed for at all in the report. Even though research has clearly shown that all types of artificial radionuclides are emitted during normal NPP operation.
To sum up, the EIA provides some information about the consequences of Hanhikivi 1; however, for getting an objective view it is necessary to consult other scientific research as well.

4.3 Identification further research needs

The literature review has revealed that there are few studies on the effects of NPP during normal operation and especially few address the effect on aquatic environments. So far, the nuclear accident at Fukushima is the only one that led to a direct discharge of large amounts of radionuclides into a marine environment. Even modelling of the effects of radioactivity on aquatic environments is scarce. Further and exact research is needed on the long-term effects of smaller amounts of radionuclides into both marine and freshwater environments. Questions like in which way flora and fauna are effected, how easily radionuclides are reactivated from sediments and what are the exact consequences of bioaccumulation are among those needing an answer.

Furthermore, no “safe exposure limit” exists for the exposure of aquatic fauna to radionuclides. Additionally, even laboratory studies done on the effect of radionuclides mainly consider a short exposure. In reality however, exposures cover long periods of time. Some studies claim that low concentrations of radionuclides are unlikely to cause serious effects on the environment; however it remains unclear what values are meant by low concentrations. More up-to-date research is needed as existing data on the effects of NPP and artificial radionuclides often is outdated. For the special case of Hanhikivi it is necessary to know exactly how fauna moves in the area; are there any stationary species, how is the activity of seals and so on.

Last but not least, the effects of artificially derived \(^{14}\text{C}\) and tritium need to be studied in more detail; especially as tritium is emitted in comparatively large amounts. As flora forms the base of the food chain, the impact of Hanhikivi 1 on python- and zooplankton needs to be research in more detail.
5 CONCLUSIONS

Bothnian Bay is unique because of its brackish water environment, leading to a unique species composition with relatively few species. Mostly consisting of particularly tolerant freshwater and marine species including several genetically unique subpopulations. Consequently, small disruptions in this environment can have significant effects on the species survival and reproduction ability; effecting the whole food web.

Consequences of the construction of a NPP at Hanhikivi are numerous. The limited water exchange between Bothnian Bay and the Bothnian Sea impedes the dilution of pollutants; despite high freshwater influx from rivers. However, evaluation of effects is challenging as there is a lack of research on the effects of NPP during normal operation and especially considering effects on the aquatic environment. Yet, there will be effects, mainly through the discharged cooling water, with negative consequences for cold-water species, a prolonged growing season and the risk for eutrophication in summer. Dredging will release contaminants such as trace metals and radionuclides from sediments. Finally, there will be increased emissions of CO$_2$ as a consequence of the removal of forest and the overall higher anthropogenic influences in the area. Certainly, the risk from any accident in the NPP is severe contamination of Bothnian Bay and surrounding waters.
6 REFERENCES


http://helcom.fi/Lists/Publications/BSEP117.pdf


Teollisuuden Voima Oyj 2006. Ympäristölupapäätös (LSY nro 13/2006/2)


FIGURE SOURCES

Figure 1 [http://www.world-nuclear-news.org/NN-Hanhikivi-investment-decision-1504144.html](http://www.world-nuclear-news.org/NN-Hanhikivi-investment-decision-1504144.html) 26/4-2016

Figure 2 [http://swedishlapland.nu/se/Bottenvikens-skargard/Aktuellt/Boundless-Bothnian-Bay---ny-webbsida/](http://swedishlapland.nu/se/Bottenvikens-skargard/Aktuellt/Boundless-Bothnian-Bay---ny-webbsida/) 26/4-2016