ECOLOGICAL PROBLEMS OF A NUCLEAR POWER STATION: A BASIS FOR COMPARING OFFSHORE SITES

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ABSTRACT

Seven possible sitings of a nuclear power station on the Belgian coast, or offshore, were postulated and compared in 1975 in a technology assessment approach.

In addition, a more detailed ecological case-study was made for one of these seven sites. An ecological (biological, sedimentological and geophysical) inventory was compiled together with evaluation of the possible effects of the warm water outfall in the particular area.

To facilitate a more accurate prediction model, and an eventual control of all ecological influences, a series of continuous and comprehensive survey programmes are needed over several years.

INTRODUCTION

This paper presents possible methods to evaluate the ecological effects of building and operating a man-made island in the North Sea, as a site for a nuclear power plant. First of all, however, the authors wish to indicate some limits of this text :

1. Only islands made of sand and stones and of an area greater than 100 hectares are considered here. Platforms and floating islands are not discussed.

2. This text speaks only about the ecological aspects of the problem. Technical, juridical and economical aspects are not dealt with.

3. Some people are convinced that certain installations which they consider as noisy or hazardous for the population are best put on offshore islands (VANDEPITTE, 1980). Other people doubt the wisdom of moving the causes of pollution from land to sea (VAN HOORN, 1979). The authors of this article do not take any position in this discussion. They only describe a method to evaluate the ecological effects of a project and to compare several possible sitings.

4. The authors limit themselves further to the effects of islands for nuclear power plants, and the studies made in the years 1973-1976 on this subject (SYMARINFRA, 1975 and HAECON-ELECTROBEL, 1976). For other industrial uses the approach will have to be different in some respects.

5. Finally the reader is reminded of the limitations of all scientific research in this field. The authors certainly do not think they have solved all problems once and for all.

   As American colleagues put it in a similar situation : "The importance of considering extremes as well as averages, the naturally great temporal and spatial variability of biological systems, the size of the (sea) being studied, the short duration of the present investigation, and the incompleteness and/or unreliability of those investigations conducted previously, are all factors adding to the difficulty of drawing readily quantifiable conclusions" (OGLESBY and ALLEE, 1969).

   Some proposals for further research are mentioned in chapter 4 of this text.

SUCCESSIVE STAGES OF RESEARCH

The technical study of such a gigantic project as a man-made island of several hundred hectares goes through different, successive stages. At the same time, the ecological studies have to progress.

One can distinguish between three successive phases :

1. To compare several possible sitings ;

2. To evaluate the effects at the chosen site ;

3. To follow-up the real phenomena before, during and after the construction of the island.

COMPARISON OF SEVERAL POSSIBLE SITINGS

3.1. Symarinfra

Symarinfra was a Belgian studygroup with as principal partners : the contractors firm N.V. L.L. & N. DE MEYER from Ghent, the Office for Industrial Promotion, DNB from Brussels, and the National Investment Company, NIM from Brussels. The Flemish Secretary of State for Regional Development asked Symarinfra to study possible industrial projects in the Belgian maritime regions.

In one of the documents HAECON made for the Symarinfra study (1975) seven possible sitings for an onshore or offshore nuclear power plant were compared. Two sites were situated onshore, five sites offshore (see fig. 1). The data-bank is presented hereafter (par. 3.2.) and the evaluation of the data is summarized (par. 3.3.).

3.2. Data collecting

a) Bathymetry and currents

The maps and currents atlas, issued by the Hydrographic Service of the Ministry of Public Works, and the articles by VAN CAUWENBERGHE (1966, 1971 and 1975) gave general information about the location and historically established stability of banks and channels, and the importance and variations of the currents.

b) Soil and subsoil

Maps established by BASTIN (1974) gave indications about the existance of sand, mud, clay, ... layers and about the geological structure of the foundation layers. These maps were the graphical results of seismic surveys and measurements of the natural radioactivity of the soil. A publication by BASTIN and MEEUSSEN (1975) was used to evaluate the sorption of released radioactive wastes by the sediments.

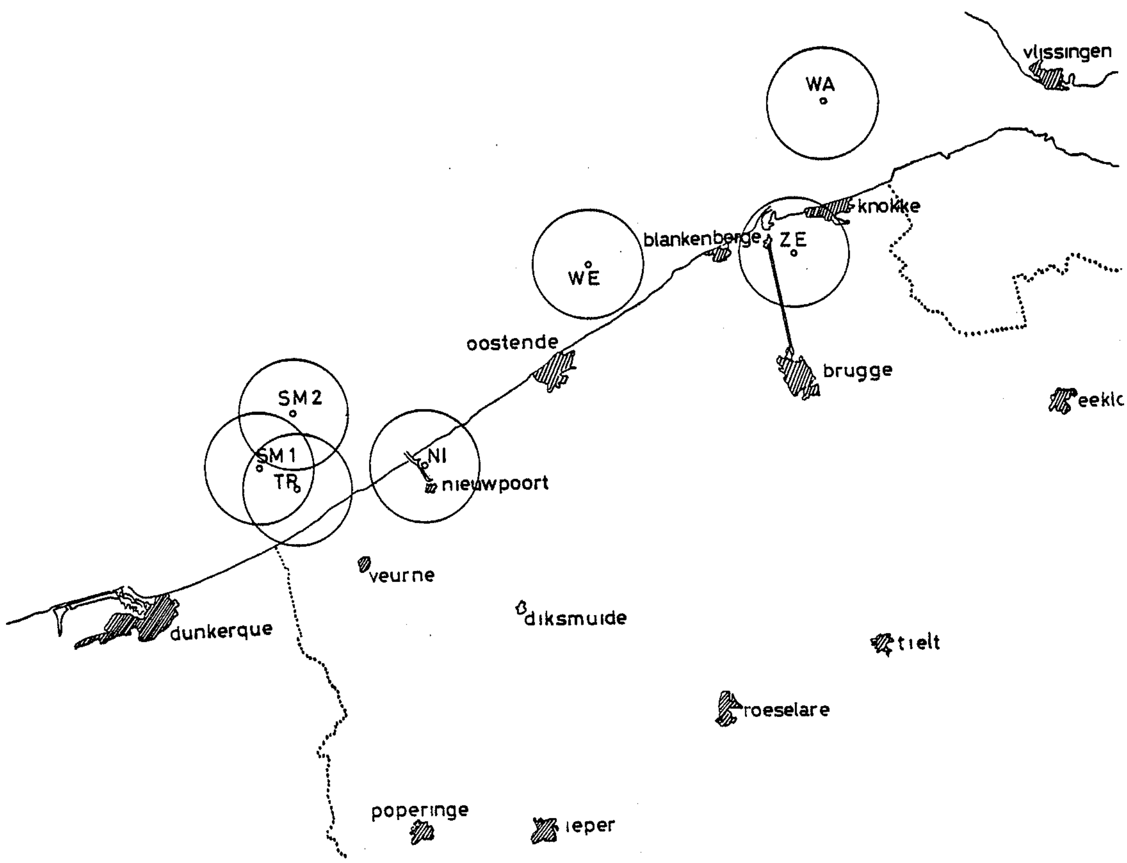

Fig. 1 : Seven possible sitings of a nuclear power plant compared in the Symarinfra-study

c) Fishing grounds

Fishermen were asked in which areas they fished regularly, seldom and never. This inquiry has resulted in the drawings of a map whereupon these zones are indicated.

d) Heating of the seawater by the discharge of cooling water from a power plant

The publications of the International Atomic Energy Agency were extremely useful for this assessment. Especially the papers by SPURR and SCRIVEN (1974) should be mentioned, as they give very practical approximative formulas.

According to SPURR and SCRIVEN the equilibrium water temperature (Ta) in a lake appropriate to a given power station heat rejection can be calculated, provided the natural water temperature (Tn) and wind speed at a height of 3 m above the water surface (u^3 in m/sec) for the period are known, along with the true area of the water surface (S) used for cooling. The formulae given are :

		in the range
H/S	= (Tn - Ta) (14,1 + 3,1 u^3) WS/m²	17-25°
	= (Tn - Ta) (15,6 + 6,0)	21-28°
	= (Tn - Ta) (16,4 + 6,5)	23-30°

SPURR and SCRIVEN remark further that, whereas the cooling capacity of rivers, lakes and cooling towers depend on heat loss to the atmosphere, in estuaries and at coastal sites the large volumes of water present are relied upon to reduce cooling water temperature by mixing.

At coastal sites the residual drift is extremely important. SPURR and SCRIVEN conclude that the tidal currents and mixing processes determine the shape of the warm water area but do not affect the effective area (S) required for eventual cooling, which can be approximately calculated by the extremely simple formula :

S = 5 x (GWE) . km², in which formula "GWE" = electrical output of a nuclear station in gigawatts.

e) Dispersion of the cooling water

The hydrographic division of the Coastal Service of the Ministry of Public Works edites an atlas of the currents in the area of the "Vlaamse Banken", the sandbanks of the Belgian continental shelf. This atlas gives the currents at the water surface every hour from 6 hours before HW to 6 hours after HW at Zeebrugge. 13 charts give the current at mean spring time. 13 charts give the current at mean neap tide. The readings are mean values and are corrected for wind influences.

Taking into account the places where the current is given and the location of the sandbanks, one divides the area into zones. One assumes the current is the same (in direction and in magnitude) in the whole zone. When there is no measurement in the zone, one assumes the current is the mean between the currents in the adjacent zones.

The charts thus drawn gave an approximation of the currents at every full hour. One further assumes that currents remain the same during each hour.

For each of the 5 offshore sites one can now approximately follow the dispersion of the cooling water, for different tides (spring, neap), for different moments of discharge (HW-6h, HW-5h, ..., HW+5h, HW+6h) and during several successive tidal cycles.

In this way one gets an impression of the cooling water dispersion. In the case of the Trapegeer Island, the problem was studied in a more sophisticated (and also much more costly) way (see par. 4.4.), to produce similar results.

This makes us think that although the method just described is very approximative, it can be useful when comparing sites.

For an island on the Westdiep-site, the method clearly indicates that all discharges after a few tidal cycles are moving to the North-East.

The graphs also clearly indicate that this is not true for an island on the Wenduinebank. The dispersion of the cooling water discharged on this site is very irregular.

The graphs also represent the dispersion of cooling water of an onshore plant when this cooling water has been brought by pipeline to that particular place for discharge. If the cooling water of an onshore nuclear power plant is discharged on or near the beaches, one assumes it will stay there in the vicinity of the outfall for a rather long time. As VAN CAUWENBERGHE (1975) has demonstrated there is very little interaction between this water and the rest of the "Vlaamse Banken" area.

f) The dispersion of radioactive wastes released in the atmosphere

Radioactive wastes released in the atmosphere can reach man directly (whole body radiation or lung radiation), or indirectly (through the food chain).

According to the U.S. Atomic Energy Agency, the total indirect radiation will be similar for onshore or offshore nuclear plants. The food chain is modified, but not the final radiation measured in man-rem.

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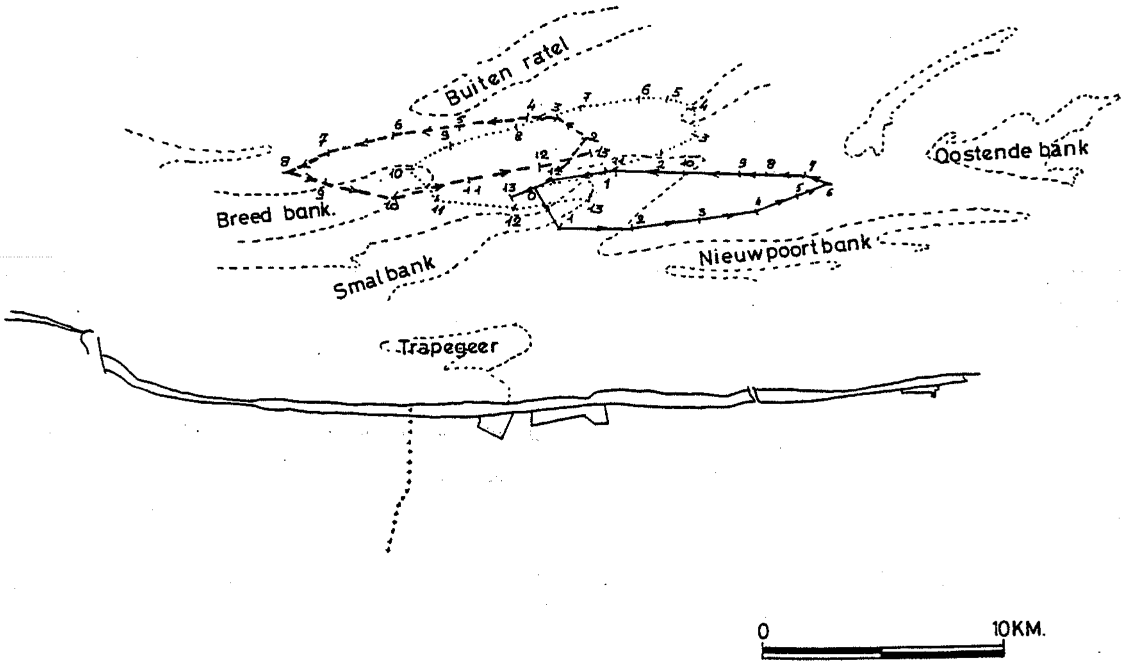

Fig. 2 : Cooling water dispersion at the Smalbank

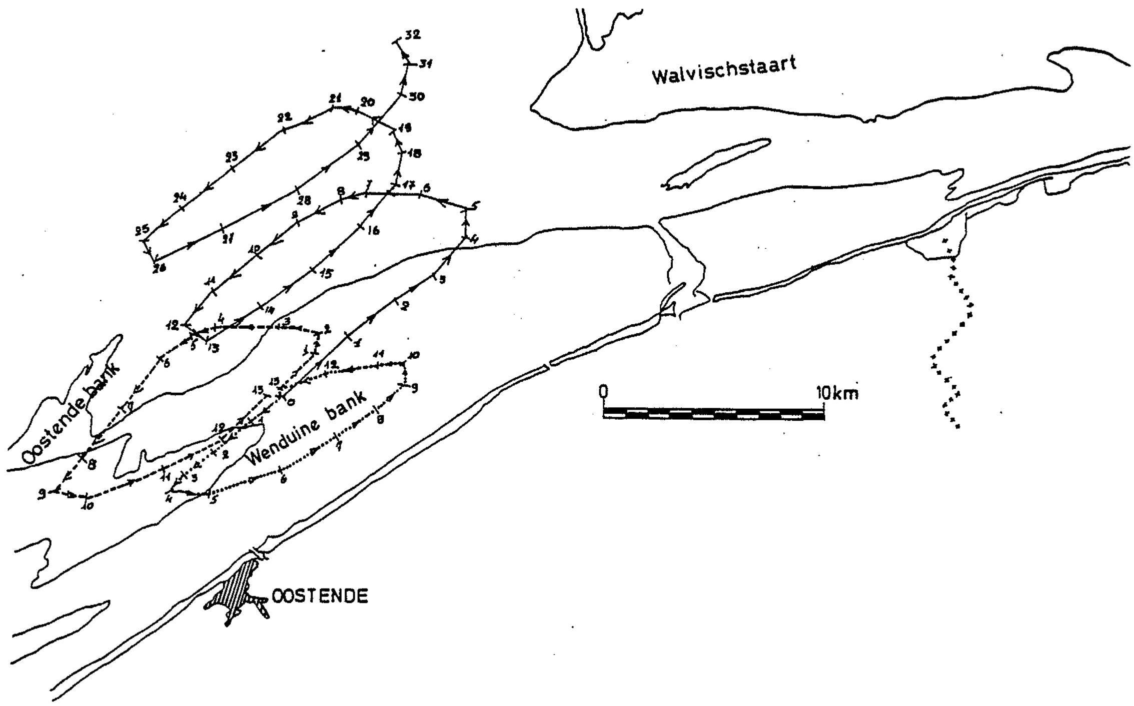

Fig. 3 : Cooling water dispersion at the Wenduinebank

For the direct radiation however, the siting can make a difference. The seven sitings were compared in the following way.

One assumes that each site is the centre of a system of polar coordinates (r, θ) with $\theta = 0$ corresponding with the North, and θ being measured counter clockwise from 0^0 to 360^0. The radiation (D) man receives at a certain location depends on the distance (r) to the plant and the prevailing wind situation (θ).

One assumes a linear correlation between radiation and its effects, so that the total influence (S) of a certain nuclear power plant (j) can be calculated as :

$$Sj = \int_0^{\infty} \int_{0^0}^{360^0} Pj\,(r, \theta)\,.\,Dj\,(r, \theta)\,.\,rdr\,.\,d\theta$$

where $Pj\,(r, \theta)$ is the population at the place (r, θ).

When the functions Pj and Dj are known for each site one can classify the seven sites in order of preference.

One approximated the double integration by double summations :

$$Sjb = \sum_{i=0}^{4} \sum_{i=0}^{11} Pj\,(r_i, \theta_k)\,Dj\,(r, \theta_k)$$

In this formula $Pj\,(r_i, \theta_k)$ is the population in the sector $(r_i < r \leqslant r_{i+1}, \theta_k < \theta \leqslant \theta_{k+1})$, with $r_o = 0$, $r_1 = 3$, $r_i = 5\,(i-1)\,(i \geqslant 2)$ and $\theta_k = 15^0 + k30^0$.

One has not only to take into account the permanent population, but also the holiday residents.

For the function $Dj\,(r_i, \theta_k)$ the following approximations were made :

1) Dj is the same for each site.

2) $Dj\,(r_i, \theta_k) = D_1\,(r_i)\,.\,D_2\,(\theta_k)$

3) For values of $D_2\,(\theta_k)$ one has used the values of the wind frequency as were measured in Ostend in the period '55-'63 at a height of 10 m, corrected for the periods of calm.

4) For the function $D_1\,(r_i)$ one finds many different forms in the literature. Furthermore, the values of this function can be greater or smaller depending on reactor type. As we only aim to compare seven sites, we are not interested in the absolute value of D(r) but only in the form of this function. For the calculation three different forms for D(r) were used, so that the sensivity of the results on this particular parameter could be estimated.

Finally one arrived at the following results :

Site of a nuclear power plant	S_{jb} in % of S_{1b}		
	Y_1	Y_2	Y_3
1 Zeebrugge	100	100	100
2 Nieuwpoort	86	82	89
3 Trapegeer	48	51	47
4 Wenduinebank	55	39	38
5 Smalbank 1	40	31	31
6 Smalbank 2	20	13	14
7 Walvischstaart	24	21	22

Table 1 : Comparison of the direct radiation of the population by the release of radiactive wastes in the atmosphere

From this list one can conclude that - during normal working of the reactor - the direct radiation of the population would be about 3 times greater for an onshore power plant in Zeebrugge when compared with an offshore power plant at Smalbank 1. For the sites Smalbank 2 and Walvischstaart the difference is about 5 to 1.

This is a particularly important result. In fact, in the case of an accident at the nuclear power plant, the direct radiation is a measure of the risk to the population, as the indirect radiation can be limited by organising the appropriate food control.

3.3. Evaluation

a) Surface occupation

When an island is built on the top of a sandbank, and the sand needed for the building of the island is also digged away on the top of a sandbank, the ecological harm caused by those works is very limited. However, if those works are done at the sides of a sandbank, hundreds of hectares of a very valuable ecosystem are destroyed.

This is true for the five offshore sites, without much difference between the sites.

b) Sorption of radioactive elements by seafloor sediments

Sorption of the radioactive elements in the seawater by the seafloor sediments is much more important at those places where the bottom consists of mud. This means that one fears that at the "Wenduinebank" the bottom will be get saturated with radioactive materials after a number of operating years of the nuclear power plant. For the four other sites where the seabottom consists mainly of sand, this problem will be almost non-existant.

c) Safety of the population

When an accident occurs at the nuclear power plant and significant quantities of radioactive wastes are released to the atmosphere, the consequences for the population will depend to a large extent on the meteorological situation at the time of the accident. Even at the best siting, the consequences can be considerable, and even at the worst siting the consequences can be minimal. However, one can classify the seven sites with regard to the general risk for the population. Offshore sites are clearly safer than onshore sites. Compared with an onshore siting at Zeebrugge-Ramskapelle, an offshore siting at Smalbank or Walvischstaart, is 2.5 to 7.7 times safer, and an offshore siting at Trapegeer or Wenduinebank is 1.8 to 2.6 times safer.

d) Dispersion of the cooling water

As a general rule one can say that - as ecosystems are very complex - it is recommendable to keep all changes as small as possible. The very good dispersion of the cooling water discharge at four of the five offshore sites is thus appreciated as being a very positive asset of those sites especially when compared with the two onshore sites. For the last site (Wenduinebank) the extremely important variations of the currents measured in situ do not permit to draw any conclusions.

A CASE STUDY

4.1. An island on the Trapegeerbank

When one site is selected for a more detailed technical study, one cannot consider the general evaluations of the previous paragraphs as being sufficient. More detailed surveying, study or bibliographical data and tests on mathematical and physical models are needed.

The case study commissioned by HAECON-ELECTROBEL which was carried out in 1973-1976 for an island on the Trapegeerbank, is an example of what such a study should consist of.

4.2. Surveying

A number of surveying programmes in-situ were carried out in order to give enough additional details about bathymetry and currents for building a reliable physical model in a hydraulic laboratory.

27 seismic Sonia profiles and 7 Zenkovitch vibrocores were part of a geophysical survey of the site.

95 bottom samples provide information about the sedimentological characteristics and the existing ecosystems in the area.

4.3. Study of bibliographical data

A complete inventory was made of all fauna and flora in the area. The way in which the existing organisms absorb and concentrate chemical and radioactive elements was analysed, and the possible influence of temperature increase in seawater. We now summarize some results from the above research, i.e. the direct and indirect influences of the temperature increases.

a) The impact of overheated seawater

According to PELSENEER (1901) whether heat shock on representatives of marine life is noxious, can be measured in five minutes. Except for eggs with a thick protective layer, he could ascertain that, if eggs, embryo's and adult organisms can resist for 5 minutes an upper limit of temperature, they all survive at least 6 hours more.This is an observation of much importance, since the inflow water of the planned nuclear power plant units would remain less than 5 minutes in the cooling transit.

Summary

a.1) All larvae die off at about 30 - 31° C.

a.2) Before attaining the absolute lethal temperature for adults, a paralytic temperature is observed, at which no food intake takes place. But two to three degrees before this paralysis, food intake lessens as well. Growth is in this time span almost nil.

a.3) The adults are more resistant.

a.4) Organisms dying off at about 31° C belong to marine life at low water mark or below, in coastal habitats.

a.5) Organisms surviving higher temperatures than 31° C belong to the tidal zone type, including onshore eggs exposed twice daily (air chilled or sun-dried, in extreme cases).

a.6) To type 4 belong the embryo's of the nectonic benthos, which always live below low water mark (including the eggs).

a.7) To type 5 belong the embryo's of the sessile and vagile benthos from the tidal zone. At ebb tide, the organisms can resist both sun or wind drying and survive in small holes in which the water can reach 28° C at 3 p.m. in august.

There is not much published over lethal figures for marine phytoplancton. We do not know if freshwater figures apply to marine forms (PERKINS, 1974). However, in freshwater, diatoms, green algae and blue-green algae may grow together in/between 20 - 40° C. But in temperatures from 20 - 30° C, the numbers of diatoms fall rather sharply, while green algae increase. Above 30° C green algae populations drop as well, while blue-green algae start really to bloom !

Everybody knows that diatoms form the major link in the alimentary chain of marine life at the larval stage. If marine diatoms follow the freshwater pattern an overheating may cause a lack of food. Engineers should know that the temperature in the cooling transit has to be kept under 30° C, not only for above described impact, but also for those hereafter.

b) Sublethal temperature influences

Apart from a few exceptions, the metabolism in "cold blooded" organisms doubles with Q10 - Rapid temperature alterations end up in an "overshoot" metabolism (HEATH and HUGHES, 1973), in which the temporary Q10 (normally constant within Q10) lies much higher than two. If the organism is kept a few hours, days (according to the species) in the higher temperature range, an eventual stabilisation in the metabolism usually results, which may be tested by the oxygen uptake, at least for non-photosynthesizing species (CAIRNS ET AL, 1975).

Sublethal temperatures can according to PEARCE (1969) cause the mussel (Mytilus edulis), the periwinkle (Littoreina littorea), the dog-whelk (Thais lapillus) and the starfish (Asterias rubens) to stop feeding, while intermittant sublethal temperatures have no effect.

Another sublethal effect for the mussel (24° C) regards fixation, mobility and congregation. Under unheated conditions mussels retract their byssys threads, so that they cluster firmly together as soon as they sense the approach of predators (starfish, crab, dog-whelk). Under sublethal conditions adult mussels remain relaxed and don't congregate by hauling in the byssus. Which suggests that the latter may become easy prey for their natural predators. So fish would have easier prey in sublethal conditioned mussels, fish being less exposed to the temperature through their mobility (PEARCE, 1969).

c) Interference of temperature in the reproduction cycle

According to NAYLOR (1965) "one might presuppose that heated effluents would lead to increased initial growth rates and precocious maturity, resulting in a decrease of adult size and perhaps shortening of the life cycle of at least some species".

GUNTER (1954) observed that the "vegatative temperature limits" of the adult are larger than the "reproduction temperature limits". Survival tests showing eurythermic organisms growing faster at temperatures of the heated effluents, do not mean that they may reproduce there, it may well be that they can only survive as a population while recruitment is kept up from the surrounding unheated fauna.

d) Competitive replacement by species resisting higher temperatures

The copepod Acartia tonsa (DANA), with a lethal temperature of 34° C, exist now in denser populations off Southampton, where significant cooling water is released (RAYMONT and CARRIE, 1964), replacing the normal boreal species Calanus Finmarchicus var Helgolandicus (Claus) and Acartia clausi (GIESBRECHT) in 4 years time (MARKOWSKI, 1962).

e) Colonisation by exotic species

According to NAYLOR (1965) Balanus amphitrite var. denticulata (DARWIN) may settle around cooling waters. The larvae are recruited from ship bottom's of tropical origin. Other organisms are cited as Mercierella enigmatica (FAUVEL) an oyster pest that was already once introduced in Belgium (LELOUP and LEFEVERE, 1952) etc.

f) Indirect influences

Toxicity of chemicals and temperature impact

Thermal lethality may be caused by tissue anoxia in aquatic organisms. Some toxic elements have a direct influence on O_2-uptake in the gills. Both activities are simulated by higher temperatures (HEATH and HUGHES, 1973).

Higher temperatures conditions mean a better diffusion and consequently a faster uptake of toxic products. Urban wastewaters increase in the touristic season in all coastal towns, creating a rising biological and chemical oxygen demand. Organisms may adjust to a certain O_2-lack, caused by the falling solubility of oxygen with rising temperature as long as no other noxious products interfere. The toxicity of chemical solutes may not exclusively be attributed to thermal pollution but as anoxia they must be (CAIRNS ET ALL, 1975) considered as an indirect influence.

Some chemicals are very noxious to some species, to others not at all. HAZAL ET AL, 1971, observed that for stickleback Gasterosteus ammonia in fresh water was much less toxic than in brackish and seawaters. Freshwater stickleback does not suffer at all from ammonia between 15 - 23° C. Seawater adapted stickleback dies in 96 hours at 15° C in 10.4 ppm. The same authors observed no influence of ammonia either in fresh- or seawater upon the striped bass (Morone (Roccus) saxatilis (WALBAUM).

4.4. Prediction of the temperature increases in the seawater

In the "Laboratoire National d'Hydraulique de France" in Chatou (France) the dispersion of the cooling water has been simulated with calorimetric tests on a physical model (scale 1/1000 and 1/100) with a fixed bottom. Those tests gave a rather qualitative result and have been completed and corrected by simulations on a mathematical model (also made by LNHF in Chatou).

These simulations led to the conclusions that the increase in the seawater temperature by 1° C or more, is limited to 18 km² for an installed capacity of 7.5 GWe. The temperature increases above 2, 3 and 4° C are respectively restricted to areas of 1.5, 0.5 and 0.15 km². The shapes of those hot water plumes are elongated parallel to the coast in the direction of the dominant tidal currents (VANDENBOSSCHE, 1978).

One also has to consider the absolute temperature in the cooling transit and just near the discharge.

According to the figures of DAUBERT & al., we may assume that in the centre of the ellipsoid warm water plume, that is at the immediate discharge point of the cooling system of the island, the unmixed maximal temperature will reach in normal wintertime at the most a mean temperature of 18° C and in normal summertime at the most 28° C (exceptional winters and summers not considered). Mixed temperature maxima (mixture with surrounding seawater) have not yet been calculated, but we estimate that these maxima lie 2 - 3° C lower. These maxima lie a bit above the mean temperatures of the Mediterranean Sea say 12 - 13° C and 27° C. That means that the mixed wintertime minima lie slightly above the mean low temperature of the Mediterranean Sea (12 - 13° C), while the mixed summer time maxima lie a bit below those of the Mediterranean (being 27° C) (S.J. LEFEVERE, 1974).

The fauna of the Belgian waters belong either to the Mediterranean-boreal or to the boreal species. In the case of hot summers, it would be best that the lowest heating, say 8° C, is accepted, giving the best chances to the representative of both fauna. In the thermal tolerance zone the maximum temperature reached may act as a control factor by influencing the metabolism which in itself defines the maximal activity (BRETT, 1964).

4.5. Evaluation

- A moderated thermal augmentation (below 8° C) is not noxious, although other factors must be considered.
- As long as the absolute temperature in the cooling transit is kept below 30° C, the larger part of the larvae may pass the heat shock.
- In the immediate vicinity of a nuclear power plant, molluces will not grow so well where feeding relaxes in higher temperatures, but at 80 m from the discharge, the condition of oysters is better than on traditional grounds.
- The warmwater plume can be good oysterspat collecting space.
- The influence of the warmwater plume beyond the 1.2° C isotherm is positive for the benthos as sole (Solea solea L), dab (Limanda limanda), plaice (Pleuronectes platessa), shrimp (Crangon crangon) and all the invertebrates on which these commercial species feed.
- The impoverishment of boreal Copepods, if not replaced by Mediterranean-boreal species, is rather unfavourable given that they are a very important food-link for all pelagic stages of fish and even for shrimp.
- Warmwater adapted plankton will be lost regularly in the surrounding cool waters. In the controlled warmwater ellipses, aquaculture of sessile species (oyster, mussel) may be interesting, since filter feeder may digest live plankton as well as seston. Preference goes to Western fishing grounds, toxic elements drifting rather eastwards.
- A higher temperature than 8° C will also shorten the reproduction period from Mediterranean boreal as from boreal forms. This can be eventually an advantage, but sufficient food (phyto- and zooplankton) may sometimes be lacking at that earlier reproduction period in the surrounding colder waters.

SURVEYING THE CHANGES IN THE ENVIRONMENT

If the decision is made to build an island for nuclear power plants in the area of the "Vlaamse Banken", a very thorough, additional ecological research and surveying programme will be set up.

In the Symarinfra-study (1975) one mentioned in particular :

1. Very extensive surveys of all ecological phenomena in the area.

2. Safety studies establishing more clearly the dispersion of the cooling water and the environmental behaviour (dispersion, sorption, pathways, ...) of all radionuclides which could be released at the island in normal and exceptional circumstances.

3. Feasibility studies for projects of aquaculture and agroculture where the heat losses of the nuclear power plant could be used.

The authors of this paper stress the importance of the first point. As the existing ecosystems are very complex, and not yet completely understood, one cannot trust the results of mathematical models if those results are not continually checked and confirmed by measurements in-situ.

The survey programmes will certainly have to examine the following aspects :

- the temperature variations of the seawater ;
- the changes of the pH, chemical composition, ...;
- concentration of radioactive elements in the ecosystems ,
- sorption by the sediments ;
- influences on growth and reproduction of the existing fauna and flora.

The survey programmes have to be carried out over long periods of time before and after the nuclear power plant is operational. Otherwise one fears that the great natural variation of all parameters involved will make it very difficult to determine the actual impact of the nuclear power plant on the environment.

The survey programmes which have started in 1977 to follow up the radioactive contamination of the Western Schelde by the cooling water discharges of the Doel nuclear power station are a useful example of what could be done (GEBEG, 1980).

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