AE-234
UDC 621.039.734

AE-234

Recipient Capacity of Tvären, a Baltic Bay

P-O. Agnedal and S. O. W. Bergström

AKTIEBOLAGET ATOMENERGI
STOCKHOLM, SWEDEN 1966

RECIPIENT CAPACITY OF TVÄREN, A BALTIC BAY

P-O Agnedal and S O W Bergström

ABSTRACT

The research station at Studsvik is situated on the Baltic coast and includes several reactors and laboratories, a waste disposal plant serving both the station and waste producers outside Studsvik. A storage plant for irradiated fuel from power reactors has also been built. A total of 850 people are employed.

The waste disposal plant was designed for a personnel of 900 using foreign information to correlate waste amounts to personnel. After a delay production has increased at a rate very close to the one expected. The composition of the waste is varied and difficult to predict. Minor amounts of fission products, active corrosion products, and fissile materials have been detected.

Most of the waste activity is released to a strait leading into the Bay. Large volumes of water with very low specific activity are released immediately off the coast.

Hydrological and dispersion data for the bay are quoted from a paper presented at the symposium mentioned below.

The Baltic has brackish water. Both the chemistry and the biology are quite different from those of marine or fresh water recipients. A short description is given of the fauna and flora and important foodwebs are discussed.

The different ways in which man is exposed to radioactivity in waste releases are dependent upon biological accumulation in living organisms and adsorption to dead materials. Fish consumption is the type of exposure which is likely to be the most critical, though it is possible that the exposure from sunbathing and fishing-gear handling could reach similar significance if conservative calculations are used. Accumulation factors from water to fish are given for iron, cobalt,and zinc.

Permissible releases have been calculated using relevant accumulation factors. Fission products and corrosion products seem to be of similar significance with regard to possible human exposure. Permission to release liquid waste is granted by water courts in Sweden and operations inspected by special authorities. As the water court procedure takes a long time and is very expensive it is suggested that the verdict should only take hydrology and the formal assumptions as to diet and behaviour of the exposed categories into account. Biological accumulation factors for different radionuclides should then be fixed by the inspecting authority and revised when necessary and without a new verdict.

Presented at the IAEA symposium on the Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters, Vienna 16-20 May, 1966.

Printed and distributed in July, 1966

LIST OF CONTENTS

	Page
Introduction	3
The Studsvik site and research station	3
Liquid waste production	3
The bay Tvären, general description	4
Topography and hydrologi	4
Chemistry	6
Flora	9
Fauna	9
Routes of exposure	10
General formulae	10
Radionuclides of special interest in the release	12
Preferred data for the capacity calculations	13
Permissible releases to Tvären	14
Discussion	15
Conclusion	17
References	20

INTRODUCTION

Nuclear energy research in Sweden has been concentrated to the research station at Studsvik. The facilities at the station are also used by research workers from other institutions outside AB Atomenergi. Studsvik is not exclusively used for research, as the company also deals with services of a more routine character, like waste disposal and fuel storage for power reactors.

The Studsvik site and research station

The site [1] is situated on the Baltic coast, about 80 km south-west of Stockholm. The country around the station is wooded to a large extent, and there is an archipelago off the coast with a large number of islands. The population density is low, especially in the immediate vicinity of the site.

The main waste-producing facilities are

- the R2 materials testing reactor, 30 MWth
- the R2-0 low power reactor, 1 MWth
- an isotope production plant
- a hot metallurgical laboratory (8 cells)
- a hot chemistry and plutonium laboratory (for up to about 200 research workers)
- a storage plant for spent power reactor fuel
- a waste treatment and disposal plant

Other institutions which do not produce large amounts of waste include two zero power reactors and two sub-critical assemblies for studies on reactor physics, a van de Graaff generator and laboratories for studies on physics, chemistry, thermodynamics, radiation protection and instrumentation.

Liquid waste production

The waste disposal system and treatment plant were designed along the lines applied at for instance Harwell. The predictions as to the volumetric flows of liquid waste turned out to be fairly accurate, whereas the activity amounts of all the different categories increased

much more slowly than expected. As the predictions were based upon per capita figures, this deviation may have been caused by the time delay between the arrival of a new research worker and the moment when he starts to produce active waste [2].

As the work at Studsvik includes many different types of research and is variable from time to time, it will always be difficult to predict the qualitative composition of the waste. No single radionuclide can therefore be said to dominate the hazards from the waste releases.

After control and necessary treatment, the liquid waste is released to the recipient along one of two routes. Small amounts of activity in large water volumes may be released together with the R2 reactor cooling water, about 1 m^3/s, through a duct leading out 100 m off the shore at Studsvik. The main part of the activity is pumped through a pipe-line, cf. figure 1, to a strait, Bergösundet, on the southern border of the bay Tvären. The pumping capacity is about 0.01 m^3/s.

THE BAY TVÄREN, GENERAL DESCRIPTION

The main liquid waste recipient for Studsvik is Tvären, an almost circular bay, enclosed between the mainland and a chain of islands to the east and south.

Topography and hydrology

A detailed report on the topographical, hydrological and diffusion characteristics of Tvären is presented in a symposium paper [3]. Some data will however be summarized below.

The bay has a volume of 409 M m^3 and a surface area of 17.5 km^2, giving an average depth of about 24 m. The greatest depth is about 80 m. Along the perimeter, east-to-south, there is a series of inlets connecting the bay with the Baltic. These inlets are more shallow than the bay itself, having depths not exceeding about 10 m.

The average flow through the bay is 200 - 250 m^3/s (20 M m^3/day). As the total volume above the level of the sills is 140 M m^3, the average exchange rate for the surface water in the bay will be once every week.

The main waste release occurs through a multi-nozzle arrangement in Bergösundet, where the average flow is 45 m^3/s. This flow

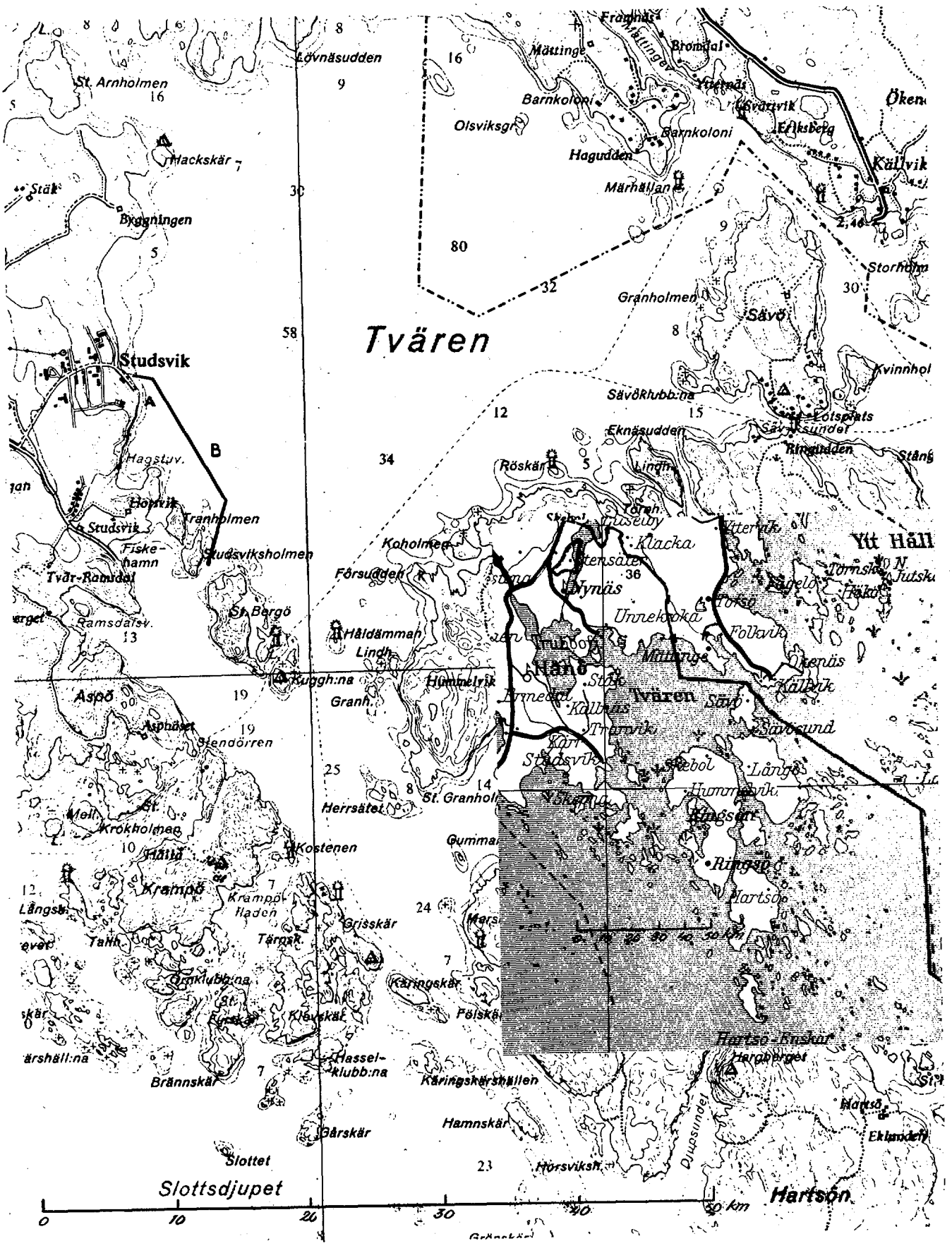

Fig. 1

A - Release of reactor cooling water

B - Pipe-line to Bergösundet

through the strait is variable as to its direction, but the variations mostly occur with fairly long period. The release arrangement has been demonstrated to give a minimum dilution of a factor 3000 - 10000 (ratio between concentration at the release point and maximum concentration in the recipient far downstream, where the initial mixing action has stopped). With the release flow 0.01 m^3/s this means that more than the whole flow through Bergösundet may be utilized for dilution. As only long time averages are relevant for permissible release calculations, it must also be possible to assume that the release is dispersed over the entire flow through Tvären, at least 200 m^3/s, if averaged over months or a year. This is emphasized by the fact that over a considerable fraction of the time the flow direction is out from the bay, making very large water volumes available for dilution.

Chemistry

The chemical and biological environment in the Baltic, as in all brackish waters, is very special, and different from both marine and fresh waters. The salinity increases from nearly zero in the northern part of the Gulf of Bothnia to around 20 °/oo in the southwestern part of the Baltic. In Tvären it varies between 5 and 7 °/oo. In Table I, a comparison is made between the composition of sea water (average values from different authors [4, 5]), the water in Tvären and the water in the Swedish lake Vättern. The values for Tvären are averages from 14 vertical series in 1963 and those for lake Vättern are averages from the investigations of Vättern in 1962 [6].

The variation in the chloride concentration in Tvären at different depths during six years is shown in figure 2.

The concentrations of iron, cobalt and zinc in Tvären are preliminary figures from our own radioactivation analyses. The values for marine water are based upon data from ref. [5]. The strontium value for Vättern is taken from Stålberg [7]. The concentrations of iron, cobalt and zinc are not for samples from Vättern but should be representative values for lake water [8].

The values in Table I support the idea that brackish water has characteristics of its own and is not just a diluted sea water.

TABLE I

Chemical composition of different waters, g/l

	A Sea Water (Cl=19°/oo)	B Tvären	C Lake Vättern	B/A	B/C
Cl	19.35	3.740	0.0051	0.19	730
SO_4	2.713	0.702	0.014	0.26	50
Ca	0.408	0.095	-	0.23	-
Mg	1.297	0.260	-	0.20	-
Na	10.769	2.103	0.0046	0.20	460
K	0.387	0.078	0.0013	0.20	60
Sr	0.0136	0.0018	43×10^{-6}	0.13	42
Si	0.004	0.001	0.0019	0.25	0.53
Fe	20×10^{-6}	280×10^{-6}	$100\text{-}500 \times 10^{-6}$	14	0.56-2.8
Co	$0.5\text{-}1 \times 10^{-6}$	0.15×10^{-6}	6×10^{-6}	0.15-0.3	0.025
Zn	5×10^{-6}	90×10^{-6}	62×10^{-6}	18	1.5

The concentration of nutrients in Tvären is rather low and varies with the depth and the season. Observations during 1963 on total phosphorus (P) and total nitrogen (N) have given the following values, in µg per litre:

		P	N
Surface (0.5 m),	maximum	35	150
	minimum	11	25
Bottom (70 m),	maximum	236	325
	minimum	30	130
Averages		42	118

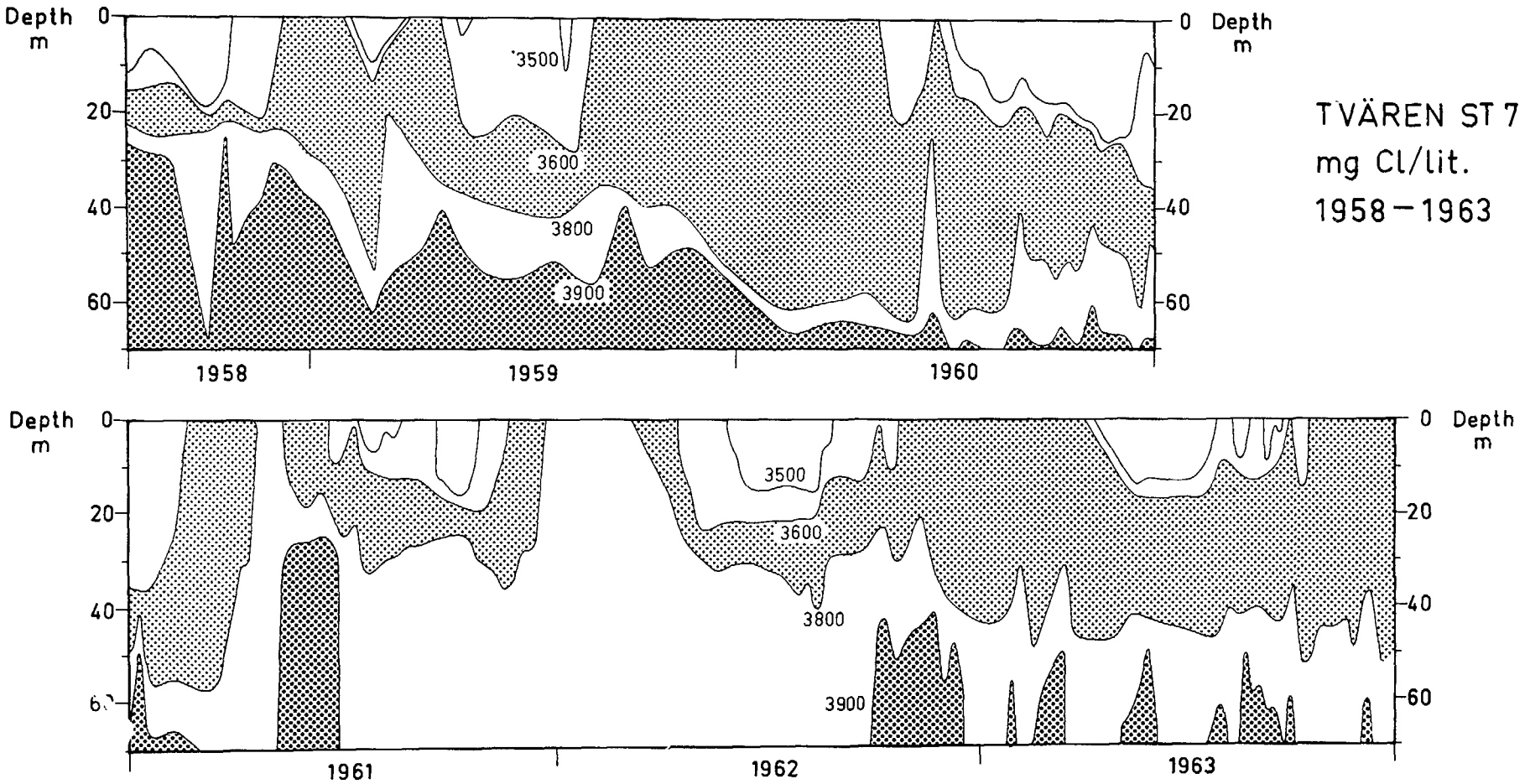
Depth
m
0
20
40
60
3500
3600
3800
3900
1958
1959
1960
1961
1962
1963
TVÄREN ST 7
mg Cl/lit.
1958 – 1963

Fig. 2

The oxygen concentration in the water is of great importance from the biological point of view. Normally the concentration is about 60 % of the saturation value down to 50 m depth and only occasionally has it been below 20 % in the deepest layer, 70 m [9]. The concentration may increase up to 90 % of saturation as far down as 70 m when the stable stratification breaks down.

Flora

The upper part (0.5 - 4 m) of the vegetation belt in Tvären is dominated by rock-weed, Fucus vesiculosus. This plant is the most common along the Swedish Baltic coast, but here in the inner parts of a sheltering archipelago it grows smaller in size and is less firmly fixed to the substratum than on open coasts. The red alga Ceramium rubrum and the green algae Cladophora glomerata, and in some places, Enteromorpha spp are common. Further down (to 10 m) red algae of the type Furcellaria and Phyllophora appear. They are either attached directly to the rocks or entangled in the byssus of Mytilus. A great number of phanerogams, Phragmites, Potamogeton, Zanichellia and Ruppia are found on sandy bottoms.

Fauna

The fauna of the Baltic or of any other brackish water in general is characterized by a small number of species with large numbers of individuals. Furthermore the growth of animals of marine origin is usually slower and the maximum size of the same species smaller in brackish water. The common mussel (Mytilus edulis) is a good example of this phenomenon. On the Swedish west coast it has a maximum size of 12 cm but in the Baltic it does not exceed 4 cm [10].

A large amount of information on the biology of Tvären is now available. The investigations have included studies on the chemistry of the water, the primary production (carbon-14 method by Steeman-Nielsen), a quantitative and qualitative study both of phyto and zooplankton and of the litoral and bottom fauna, and the species composition of sessile algae. The results are not yet published, but the primary production values indicate a low productivity of the water.

The fauna of this part of the Swedish east coast has been described by Forsman [11], who has also analysed the samples of the bottom fauna taken in Tvären as a consultant to AB Atomenergi.

On soft bottoms, the results show a very strong dominance of crustacea of the genus Pontoporeia (affinis and femorata) and of the mollusc Macoma baltica. A density of 2680 individuals per m^2 has been observed for the former but a normal value is about 60 individuals per m^2. Macoma baltica has a maximum observed density of about 500 individuals per m^2.

The most common fish species are pike, (Esox lucius), perch (Perca fluviatilis), roach (Leuciscus rutilus), burbot (Lota lota) of fresh origin water, and Baltic herring (Clupea harengus), flounder (Pleuronectes flesus) of marine origin. In the last five years bullhead (Cottus quadricornis) has become very common. From economical point of view the Baltic herring is the most important species followed by pike and perch.

The stomach content of some fish species has been examined in connection with the control of the radioactivity levels in different biota. In this way we have obtained information on various food chains, such as:

Bottom sediment - mollusc (Macoma baltica) - flounder (Pleuronectes flesus).

Suspended matter - mollusc (Mytilus edulis) - roach (Leuciscus rutilus) - pike (Esox lucius).

Plankton - baltic herring (Clupea harengus) - pike (Esox lucius).

ROUTES OF EXPOSURE

General formulae

Among the different routes by which liquid waste activity may be transported back to man, some of the more important have been discussed in a publication from the IAEA [12]. Under special conditions other routes may involve greater hazards, but the dominating ones are usually taken to be

1. the fish consumption of a population group living close to the recipient
2. professional fishermen working close to the release point
3. sun bathers on the shores of the recipient.

The permissible dose in each of the three cases are defined in the recommendations of the ICRP [13]. For the first group it corresponds to a total body dose rate of 0.5 rem/year, for the second 1.5 rems/year and for the third 0.5 rem/year.

In the case of fish consumption the requirement will be that the annual activity intake is kept below 0.1 of the intake permissible for radiological workers. The permissible annual release, Q_F, according to this condition will be

$$Q_F = \frac{31500\, V \cdot U \cdot q}{m \cdot A_F} \quad \text{Ci/year} \qquad (1)$$

$V \cdot U$ = nominal dilution flow, (V = release flow, m^3/s; U = dilution factor) m^3/s

q = permissible annual intake, μCi

m = fish consumption, kg/year

A_F = accumulation factor, water to fish

In the case of fishermen handling contaminated fishing gear one assumes (according to [12]) that the activity content of the gear is 0.1 of that in algae from the recipient. Limiting the contact dose to 1.5 rems/year gives then, according to the same reference, a permissible annual release, Q_G, of

$$Q_G = \frac{440\, V \cdot U \cdot 10^6}{E \cdot t_G \cdot A_A} \quad \text{Ci/year} \qquad (2)$$

E = mean energy of radiation per disintegration of the radionuclide in question, MeV

t_G = fishing gear handling time, hours/year

A_A = accumulation factor, water to algae

In the third case it is assumed that the shore material consists of nothing but algae from the recipient, and that the sun bathers lie directly upon this material. The same type of calculation as for the fishing gear handling gives a permissible release, Q_S, of

$$Q_S = \frac{15\ V \cdot U \cdot 10^6}{E \cdot t_S \cdot A_A} \quad \text{Ci/year} \qquad (3)$$

t_S = total time spent sunbathing, hours/year.

Radionuclides of special interest in the release

One has to pick out a finite number of radionuclides of principal interest when investigating the recipient capacity. Choosing these nuclides is a difficult matter, as one has to consider not only half-life, radiotoxicity, physical, chemical and biological transport and concentration processes in the recipient, but also technical and economical factors for the plant using the recipient. Such factors may be activity production rates, the quality of the containment in each case and the cost for waste treatment to bring activity levels down to what is permissible.

Fission products like strontium-90, cesium-137 and ruthenium-106 are produced at high rates in reactor fuel and are all very radiotoxic. They are, however, well contained in the reactor fuel, whereas activation products like iron-59, cobalt-60 and zinc-65 are not so well contained, as they have one barrier less against the environment. Plutonium-239 has fairly low radiotoxicity if ingested (and not inhaled) and it is usually well contained, like the fission products. Low radiotoxicity and short half-lives of a large number of radionuclides make it unnessary to study them.

It seems likely that the activation products iron, cobalt and zinc will cause higher exposures to man from liquid releases than other radionuclides. They are produced in large volumes of water, are difficult and expensive to treat, and are often accumulated to a great extent by organisms. Fission products and plutonium are contained in smaller volumes, are cheaper to treat or store, and most of them are not biologically concentrated to any high degree. It is not possible to purify waste from tritiated water, but economical reasons and the rate at which

the nuclide is formed make tritium release negligible in all but the smallest of recipients. It has only been studied here for comparison.

Preferred data for the capacity calculations

To make a calculation of the activity amounts which may safely be released to Tvären the following parameters have to be determined:

1. Accumulation factors, A_F and A_A, for the nuclides involved, from water to fish and algae, respectively.
2. The annual fish consumption, m, of the people taking their fish from the recipient
3. The time, t_G, fishermen handle contaminated gear.
4. The time, t_S, spent sunbathing on the shores.

The data for the accumulation factors from water to fish are fairly well known in this type of biotope. Stable strontium has been investigated by Agnedal [14]. The accumulation factor for cesium has been calculated from our fall-out-measurements in Tvären [9]. Preliminary values for stable iron, cobalt and zinc are available from the investigation mentioned above. Accumulation factors for ruthenium and plutonium, however, have had to be taken from the literature.

The preferred values for accumulation factors are given in Table II.

TABLE II

Data for the radionuclides studied

E MeV/dis.	Permissible annual intake x) µCi	Radio-nuclide	A_F	A_A
-	2400	^{3}H	1	-
1.3	40	^{59}Fe	70	3000
2.6	24	^{60}Co	70	3000
1.45	80	^{65}Zn	100	3000
1.1	0.3	^{90}Sr	1	100
1.4	8	^{106}Ru	300	3000
0.85	16	^{137}Cs	300	300
-	4	^{239}Pu	30	-

x) according to ICRP 1962

The average fish consumption in Sweden is 13.2 kg/yr - disregarding canned and prepared fish. With these latter categories included the figure increases to 18.6 kg/yr [15]. There are reasons to believe that the population around Tvären has a higher consumption than the average, maybe 30 kg/yr. This per capita figure gives a total consumption by the fishermen and their families - less than 100 persons - of about 3 t/yr. Their consumption would then be 15 % of the total catch in Tvären, 20 t/yr, which seems to be a reasonable fraction.

The fishermen will at most use 3000 h/yr in contact with their gear.

For Swedish conditions the time spent sunbathing will probably not exceed 100 h/yr.

PERMISSIBLE RELEASES TO TVÄREN

Using the data in Table II, the formulae (1) - (3) render permissible releases for each route of exposure as shown in Table III.

Note that permissible releases considering handling of fishing gear on one hand and sunbathing on the other hand will be identical, when times t_G and t_S are chosen as 3000 and 100 h/yr, respectively.

TABLE III

Permissible releases of different radionuclides

Radionuclide	Permissible releases, Ci/yr considering		
	fish consumption	fishing gear or sunbathing IAEA	GAMMA[x]
^{3}H	$500 \cdot 10^{6}$	∞	∞
^{59}Fe	120000	7700	30000
^{60}Co	72000	3800	15000
^{65}Zn	170000	6900	70000
^{90}Sr	63000	270000	∞
^{106}Ru	5600	7100	18000
^{137}Cs	110000	120000	650000
^{239}Pu	28000	∞	∞

x) cf. "Discussion"

DISCUSSION

This type of recipient capacity calculation will generally result in overestimates of the hazards. To stay always below permissible levels, waste disposal has to be managed so that the average releases are far below the maximum. Simplification of the release activity determinations usually leads to treating unspecified activity as if it had the most unfavourable composition. Furthermore, the discussions of critical routes of exposure include a number of assumptions of conservative character. They will then apply strictly to a very small group of people, or maybe only to a hypothetical, non-existent individual.

The diffusion data used in this study are well established, and verified in several independent series of experiments. Possible errors are small and certainly on the safe side.

A special problem is the direct release to Tvären, but also here it has been shown that the initial dilution is satisfactory, especially as only small amounts of activity are released this way. The exchange of surface water in the bay, down to 10 metres depth, is fairly rapid too. It seems therefore that it might even be possible to release the main part of the activity here instead of at Bergösundet.

Earlier we have tried to calculate the capacity of brackish water recipients through interpolation between marine and fresh water data. From Table I it is readily seen that this is not a very satisfactory approach, an observation which is further emphasized by results from our studies of accumulation processes in the Baltic. Special data for this type of biotope are necessary if large safety margins are to be avoided.

No food chains of interest can be found other than the consumption of a few species of fish. Mussels or other types of seafood from this recipient are not used as food. The relevant figure for annual fish consumption should probably be lower than has been assumed here, as a large fraction of the fish catch in Tvären consists of non-stationary fish. Marking experiments have shown that Baltic herring come into Tvären for spawning during spring or early summer and stays about three months, after which they are found in different parts of the southern Baltic. Other species like flounder and pike move in and out of Tvären but not over such long distances. The fish catch from Tvären is used

for direct consumption and no fish industry is based on the harvest from Tvären. This makes it safe to calculate the accumulation only to fish muscle tissue and not to bone.

Exposure from the handling of fishing gear and sunbathing on the beaches has been calculated according to the IAEA method [12]. This approximates these exposures as coming from a semi-infinite source consisting of contaminated seaweeds, algae or plankton to 100 % for the beaches, and to 10 % for the fishing gear. The beta contact dose is included in these calculations, which does not seem to be relevant for the total body exposure to which the permissible doses are applicable. Higher permissible releases are obtained if we instead approximate the sources as large discs (radius 100 m) from which only the gamma radiation is considered. The last column "GAMMA", in Table III shows representative values from these calculations. In these we have assumed 1 kg organic matter per m^2 fishing gear and 15 kg per m^2 beach. Perpendicular distances from source to critical organs have been set at 0.5 and 0.05 m, respectively. Also here safety margins are included - the large size of the sources assumed, no attenuation of the radiation in air and no self-absorption in the source.

It should be observed that if 100 hours of sunbathing on a beach results in a dose of 0.5 rem, then the dose rate would be as high as 5 rems/h. This is easily detected as it is 500 times higher than the background in most places.

The accumulation factors for algae and plankton are as yet not very well known for this type of recipient. This has made it necessary to use conservative values for A_A. The values for the accumulation factors for iron, cobalt and zinc, given in Table II, are maximum values. The samples analysed to date have given the following mean values: iron 50, cobalt 30 and zinc 130. Values from Windscale [16] give accumulation factors for iron and cobalt of the same order of magnitude but a higher value for zinc, 3500. The latter discrepancy may depend on a great difference in zinc content of the water (cf Table I). It should be observed that the Windscale values are for total fish and ours refer to muscle tissue only. Mauchline [17] found an accumulation factor in fish flesh for cesium of 100 and the same for ruthenium. We have determined a factor of 300 for cesium. As ruthenium appears in particulate form the accumulation will

probably not exceed that for cesium, so that the use of similar accumulation factors for these two nuclides seems appropriate. Recently Preston [18] has shown that the accumulation factor in fish flesh for ruthenium varies between 8 and 80 in Windscale.

The only information on the accumulation of plutonium in fish is found in an investigation from the Pacific [19] and reported to be only 3. Ward [20] has reported the same accumulation of plutonium in lobster flesh. With regard to the very few values found we have applied a safety factor using the accumulation factor 30.

Concerning the accumulation in algae it is questionable if one should use the accumulation in plankton or in sessile algae. As it is the material washed up on the shore where sun bathers will lie which forms the radiation source it seems more correct to use accumulation in plankton. In order to be conservative we have chosen to take the highest accumulation factors for either plankton or sessile algae.

One cannot exclude the possibility that some other radionuclide than the ones studied here might become the critical one. Any rules for the limitation of permitted releases to the recipient should allow for this possibility.

CONCLUSION

Releases of liquid waste in Sweden have to be approved by water courts. This is often a tedious and expensive procedure. The present verdicts applying to the Studsvik research station are based upon a study made in 1956/57. The verdicts specify the activity amounts within different categories which may be released, Table IV [1]. In 1957, no special category was specified for tritium, which necessitated a new court procedure in 1965 to amend the verdict in this respect, though there was no change in the evaluation of the recipient capacity or of the extent to which this capacity was to be utilized.

Therefore, it seems desirable from several points of view to get release permits formulated in a slightly different way. This formulation should allow simple control methods at the waste disposal station when releases are far below permissible figures, using categories like "total alpha" and "total beta". Rising amounts of activity released should

then correspond to more detailed information on the composition. The formula should provide release limits for all types of radionuclides where permissible intake and accumulation factors may be defined.

TABLE IV

Release limits for Studsvik waste to Tvären (Bergösundet)

Radionuclide	1965 water court verdict x) Ci/yr	Present calculation Ci/yr
Tritium	72000	$500 \cdot 10^6$
Other beta emitters	396	5600 - ^{106}Ru, fish (3800 - ^{60}Co, algae)
including less than		
for Ce, Y, rare earths	180	
for ^{89}Sr, ^{90}Sr	29	63000 - ^{90}Sr, fish
Alpha emitters	2.4	28000 - ^{239}Pu, fish

x) A safety factor of 10 has been applied.

If several radionuclides occur at significant levels in the release, one would also have to take into account possible superposition of exposures. This may also have to be considered in the case of individuals exposed by several routes of exposure.

One would then arrive at a release rule of the type

$$2 \sum \frac{Q_\nu}{Q_{o\nu}} < 1 \qquad (4)$$

where Q_ν is the release in Ci/yr of the radionuclide ν, and $Q_{o\nu}$ is the most restrictive value, Q_F, Q_G, or Q_S, for permissible release of that nuclide alone, calculated according to equations (1) - (3). The factor 2 in eq. (4) has been used to safeguard against simultaneous exposure by more than one route.

Where water court procedures apply, the verdict should not explicitly include release values for specific nuclides. It should instead contain formulae of types (1) - (4) and give accepted values for the nominal dilution flow $V \cdot U$, for the fish consumption m, and for the exposure times t_G and t_S. Data for the accumulation factors A_A and A_F, for permissible intakes q and for E should only be exemplified for some radionuclides of interest. The proper values to apply should instead be determined by competent authorities, who should also have to revise them in the light of any new information obtained. It would then be possible to keep the release rules in accordance with the latest knowledge in the field, and flexible enough to meet changes in the waste composition, without repeated proceedings.

Finally, it is evident that the accumulation factors A_A for various radionuclides in brackish water have to be better known if eqs. (2) and (3) are used, as they determine the release limits in many cases. However, it has been suggested here that more realistic calculations would give larger permissible releases for these routes of exposure. It would be of great value, if such more realistic approaches could be universally accepted. Calculations would then give fish or sea food consumption as the dominating route of exposure under most circumstances. We find convincing evidence that this is the case also in reality.

REFERENCES

1. BERGSTRÖM, S O W,
Studsvik and its environment from a waste disposal viewpoint. 1965. (AB Atomenergi, Sweden, Internal report SSS-143.)

2. LINDHE, S, LINDER, P,
The handling of liquid waste at the research station of Studsvik, Sweden. 1965 (AE-182).

3. GYLLANDER, Ch,
Water exchange and diffusion processes in Tvären, a Baltic bay. 1966. (SM 72/12, presented at The Symposium on Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters, Vienna 16-20 May, 1966.)

4. BARNES, H,
The ionic composition of sea water.
J. Exp. Biol. 31 (1954) 582.

5. SVERDRUP, H U, JOHNSON, M W, FLEMING, R H,
The Oceans. Their physics, chemistry, and general biology.
Prentice-Hall, Englewood Cliffs N.J. 1955.

6. KARLGREN, L,
Nat. Water Protection Service, Stockholm, Sweden.
Personal com. 1966.

7. STÅLBERG, N,
Lake Vättern. 1939. (Acta Phytogeographica Suecica No. 11.)

8. HUTCHINSON, G E,
Treatise on Limnology, Vol. 1. Wiley, New York 1957.

9. AGNEDAL, P-O,
Measurements on background and fall-out radioactivity in samples from the Baltic Bay of Tvären, 1957-1963. 1965. (AE-171.)

10. REMANE, A, SCHLIEPER, C,
Die Biologie des Brackwassers. Schweiz, Verlagsb., Stuttgart 1958. (Die Binnengewässer, Bd 22.)

11. FORSMAN, B,
Notes on the invertebrate fauna of the Baltic.
Archiv Zool. Ser. 2, 9 (1956) 17.

12. Radioactive waste disposal into the sea. Vienna 1961. (I.A.E.A. Safety Series No. 5.)

13. Recommendations of ICRP (As amended 1959 and rev. 1962). Oxford 1964. (ICRP Publ. 6.)

14. AGNEDAL, P-O,
Calcium and strontium in Swedish waters and fish, and accumulation of strontium-90. 1966. (AE-224.) Also presented at the Int, Symp. Radioecological Conc. Proc. Stockholm, April 1966.

15. Statistical abstract of Sweden (Statistisk årsbok för Sverige), 52 (1965).

16. MAUCHLINE, J,
A review of the biological significance of certain neutron induced radio-isotopes in the marine environment. 1961.
(UKAEA , PG Report 248 (W).)

17. MAUCHLINE, J,
The biological and geographical distribtution in the Irish sea of radioactive effluent from Windscale works 1959 to 1960.
1963. (UKAEA, AHSB (RP) R 27.)

18. PRESTON, A,
Personal com., X-18/K, Int. Symp. Radioecological Conc.
Proc. Stockholm, April 1966.

19. PILLAI, K C, SMITH, R C, FOLSOM, T R,
Plutonium in the marine environment.
Nature 203 (1964) 568.

20. WARD, E E,
Uptake of Plutonium by the lobster, Homarus vulgaris.
Nature 209 (1966) 625.

LIST OF PUBLISHED AE-REPORTS

1—157. (See the back cover earlier reports.)

158. A study of the angular distributions of neutrons from the Be^9 (p,n) B^9 reaction at low proton energies. By. B. Antolkovic', B. Holmqvist and T. Wiedling. 1964. 19 p. Sw. cr. 8:—.

159. A simple opparatus for fast ion exchange separotions. By K. Samsahl. 1964. 15 p. Sw. cr. 8:—

160. Measurements of the Fe^{54} (n, p) Mn^{54} reaction cross section in the neutron energy range 2.3—3.8 MeV. By A. Lauber and S. Malmskog. 1964. 13 p. Sw. cr. 8:—.

161. Comparisons of measured ond colculated neutron fluxes in laminated iron and heavy water. By. E. Aalto. 1964. 15 p. Sw. cr. 8:—.

162. A needle-type p-i-n junction semiconductor detector for in-vivo measurement of beta tracer activity. By A. Lauber and B. Rosencrantz. 1964. 12 p. Sw. cr. 8:—.

163. Flame spectro photometric determination of strontium in water ond biological materiol. By G. Jönsson. 1964. 12 p. Sw. cr. 8:—.

164. The solution of a velocity-dependent slowing-down problem using case's eigenfunction expansion. By A. Claesson. 1964. 16 p. Sw. cr. 8:—.

165. Measurements of the effects of spacers on the burnout conditions for flow of boiling water in a vertical annulus and a vertical 7-rod cluster. By K. M. Becker and G. Hernberg. 1964. 15 p. Sw. cr. 8:—.

166. The transmission of thermal ond fast neutrons in oir filled annular ducts through slabs of iron and heovy water. By J. Nilsson and R. Sandlin. 1964. 33 p. Sw. cr. 8:—.

167. The radio-thermoluminescense of $CaSO_4$: Sm and its use in dosimetry. By B. Bjärngard. 1964. 31 p. Sw. cr. 8:—.

168. A fast radiochemical method for the determination of some essential trace elements in biology and medicine. By K. Samsahl. 1964. 12 p. Sw. cr. 8:—.

169. Concentration of 17 elements in subcellular fractions of beef heart tissue determined by neutron activation analysis. By P. O. Wester. 1964. 29 p. Sw. cr. 8:—.

170. Formotion of nitrogen-13, fluorine-17, and fluorine-18 in reactor-irradiated H_2O and D_2O and applications to activation analysis and fast neutron flux monitoring. By L. Hammar and S. Forsén. 1964. 25 p. Sw. cr. 8:—.

171. Measurements an background and fall-out radioactivity in samples from the Baltic bay of Tvären, 1957—1963. By P. O. Agnedal. 1965. 48 p. Sw. cr. 8:—

172. Recoil reactions in neutron-activation analysis. By D. Brune. 1965. 24 p. Sw. cr. 8:—.

173. A parametric study of a constant-Mach-number MHD generator with nuclear ionization. By J. Braun. 1965. 23 p. Sw. cr. 8:—.

174. Improvements in applied gamma-ray spectrometry with germanium semiconductor detector. By D. Brune, J. Dubois and S. Hellström. 1965. 17 p. Sw. cr. 8:—.

175. Analysis of linear MHD power generators. By E. A. Witalis. 1965. 37 p. Sw. cr. 8:—.

176. Effect of buoyancy on forced convection heat transfer in vertical channels — a literature survey. By A. Bhattacharyya. 1965. 27 p. Sw. cr. 8:—.

177. Burnout data for flow of boiling water in vertical round ducts, annuli and rod clusters. By K. M. Becker, G. Hernborg, M. Bode and O. Eriksson. 1965. 109 p. Sw. cr. 8:—.

178. An analytical and experimental study of burnout conditions in vertical round ducts. By K. M. Becker. 1965. 161 p. Sw. cr. 8:—.

179. Hindered El transitions in Eu^{155} and Tb^{161}. By S. G. Malmskog. 1965. 19 p. Sw. cr. 8:—.

180. Photomultiplier tubes for low level Cerenkov detectors. By O. Strindehag. 1965. 25 p. Sw. cr. 8:—.

181. Studies of the fission integrals of U235 and Pu239 with cadmium and boron filters. By E. Hellstrand. 1965. 32 p. Sw. cr. 8:—.

182. The handling of liquid waste at the research station of Studsvik, Sweden. By S. Lindhe and P. Linder. 1965. 18 p. Sw. cr. 8:—.

183. Mechanical and instrumental experiences from the erection, commissioning and operation of a small pilot plant for development work on aqueous reprocessing of nuclear fuels. By K. Jönsson. 1965. 21 p. Sw. cr. 8:—.

184. Energy dependent removal cross-sections in fast neutron shielding theory. By H. Grönroos. 1965. 75 p. Sw. cr. 8:—.

185. A new method for predicting the penetration and slowing-down of neutrons in reactor shields. By L. Hjärne and M. Leimdörfer. 1965. 21 p. Sw. cr. 8:—.

186. An electron microscope study of the thermal neutron induced loss in high temperature tensile ductility of Nb stabilized austenitic steels. By R. B. Roy. 1965. 15 p. Sw. cr. 8:—.

187. The non-destructive determination of burn-up means of the Pr-144 2.18 MeV gamma activity. By R. S. Forsyth and W. H. Blackadder. 1965. 22 p. Sw. cr. 8:—.

188. Trace elements in human myocardial infarction determined by neutron activation analysis. By P. O. Wester. 1965. 34 p. Sw. cr. 8:—.

189. An electromagnet for precession of the polarization of fast-neutrons. By O. Aspelund, J. Björkman and G. Trumpy. 1965. 28 p. Sw. cr. 8:—.

190. On the use of importance sampling in particle transport problems. By B. Eriksson. 1965. 27 p. Sw. cr. 8:—.

191. Trace elements in the conductive tissue of beef heart determined by neutron activation analysis. By P. O. Wester. 1965. 19 p. Sw. cr. 8:—.

192. Radiolysis of aqueous benzene solutions in the presence of inorganic oxides. By H. Christensen. 12 p. 1965. Sw. cr. 8:—.

193. Radiolysis of aqueous benzene solutions at higher temperatures. By H. Christensen. 1965. 14 p. Sw. cr. 8:—.

194. Theoretical work for the fast zero-power reactor FR-0. By H. Häggblom. 1965. 46 p. Sw. cr. 8:—.

195. Experimental studies on assemblies 1 and 2 of the fast reactor FR0. Part 1. By T. L. Andersson, E. Hellstrand, S-O. Londen and L. I. Tirén. 1965. 45 p. Sw. cr. 8:—.

196. Measured and predicted variations in fast neutron spectrum when penetrating laminated Fe-D_2O. By E. Aalto, R. Sandlin and R. Fräki. 1965. 20 p. Sw. cr. 8:—.

197. Measured and predicted variations in fast neutran spectrum in massive shields of water and concrete. By E. Aalto, R. Fräki and R. Sandlin. 1965. 27 p. Sw. cr. 8:—.

198. Measured and predicted neutron fluxes in, and leakage through, a configuration of perforated Fe plates in D_2O. By E. Aalto. 1965. 23 p. Sw. cr. 8:—.

199. Mixed convection heat transfer on the outside of a vertical cylinder. By A. Bhattacharyya. 1965. 42 p. Sw. cr. 8:—.

200. An experimental study of natural circulation in a loop with parallel flow test sections. By R. P. Mathisen and O. Eklind. 1965. 47 p. Sw. cr. 8:—.

201. Heat transfer analogies. By A. Bhattocharyyo. 1965. 55 p. Sw. cr. 8:—.

202. A study of the "384" KeV complex gamma emission from plutonium-239. By R. S. Forsyth and N. Ronqvist. 1965. 14 p. Sw. cr. 8:—.

203. A scintillometer assembly for geologicol survey. By E. Dissing and O. Landström. 1965. 16 p. Sw. cr. 8:—.

204. Neutron-activation analysis of natural water applied to hydrogeology. By O. Landström and C. G. Wenner. 1965. 28 p. Sw. cr. 8:—.

205. Systematics of absolute gamma roy transition probabilities in deformed odd-A nuclei. By S. G. Malmskog. 1965. 60 p. Sw. cr. 8:—.

206. Radiation induced removal of stacking foults in quenched aluminium. By U. Bergenlid. 1965. 11 p. Sw. cr. 8:—.

207. Experimental studies on assemblies 1 and 2 of the fast reoctor FR0. Part 2. By E. Hellstrand T. L. Andersson, B. Brunfelter, J. Kockum, S-O. Londen and L. I. Tirén. 1965. 50 p. Sw. cr. 8:—.

208. Measurement of the neutron slowing-down time distribution ot 1.46 eV and its space dependence in woter. By E. Möller. 1965. 29. p. Sw. cr. 8:—.

209. Incompressible steady flow with tensor conductivity leaving a transverse magnetic field. By E. A. Witalis. 1965. 17 p. Sw. cr. 8:—.

210. Methods for the determination of currents and fields in steady two-dimensional MHD flow with tensor conductivity. By E. A. Witalis. 1965. 13 p. Sw. cr. 8:—.

211. Report on the personnel dosimetry at AB Atomenergi during 1964. By K. A. Edvardsson. 1966. 15 p. Sw. cr. 8:—.

212. Central reactivity measurements on assemblies 1 and 3 of the fast reactor FR0. By S-O. Londen. 1966. 58 p. Sw. cr. 8:—.

213. Low temperature irradiation applied to neutron activation onalysis of mercury in human whole blood. By D. Brune. 1966. 7 p. Sw. cr. 8:—.

214. Characteristics of linear MHD generators with one or a few loads. By E. A. Witalis. 1966. 16 p. Sw. cr. 8:—.

215. An automated anion-exchange method for the selective sorption of five groups of trace elements in neutron-irradiated biological material. By K. Samsahl. 1966. 14 p. Sw. cr. 8:—.

216. Measurement of the time dependence of neutron slowing-down and thermalization in heavy water. By E. Möller. 1966. 34 p. Sw. cr. 8:—.

217. Electrodeposition of actinide and lanthanide elements. By N-E. Bärring. 1966. 21 p. Sw. cr. 8:—.

218. Measurement of the electrical conductivity of He^3 plasma induced by neutron irradiation. By J. Braun and K. Nygaard. 1966. 37 p. Sw. cr. 8:—.

219. Phytoplankton from Lake Magelungen, Central Sweden 1960—1963. By T. Willén. 1966. 44 p. Sw. cr. 8:—.

220. Measured and predicted neutron flux distributions in a material surrounding av cylindrical duct. By J. Nilsson and R. Sandlin. 1966. 37 p. Sw. cr. 8:—.

221. Swedish work on brittle-fracture problems in nuclear reactor pressure vessels. By M. Grounes. 1966. 34 p. Sw. cr. 8:—.

222. Total cross-sections of U, UO_2 and ThO_2 for thermal and subthermal neutrons. By S. F. Beshai. 1966. 14 p. Sw. cr. 8:—.

223. Neutron scattering in hydrogenous moderators, studied by the time dependent reaction rate method. By L. G. Larsson, E. Möller and S. N. Purohit. 1966. 26 p. Sw. cr. 8:—.

224. Calcium and strontium in Swedish waters and fish, and accumulation of strontium-90. By P-O. Agnedal. 1966. 34 p. Sw. cr. 8:—.

225. The radioactive waste management at Studsvik. By R. Hedlund and A. Lindskog. 1966. 14 p. Sw. cr. 8:—.

226. Theoretical time dependent thermal neutron spectra and reaction rates in H_2O and D_2O. By S. N. Purohit. 1966. 62 p. Sw. cr. 8:—.

227. Integral transport theory in one-dimensional geometries. By I. Carlvik. 1966. 65 p. Sw. cr. 8:—.

228. Integral parameters of the generalized frequency spectra of moderators. By S. N. Purohit. 1966. 27 p. Sw. cr. 8:—.

229. Reaction rate distributions and ratios in FR0 assemblies 1, 2 and 3. By T. L. Andersson. 1966. 50 p. Sw. cr. 8:—.

230. Different activation techniques for the study of epithermal spectra, applied to heavy water lattices of varying fuel-to-moderator ratio. By E. K. Sokolowski. 1966. 34 p. Sw. cr. 8:—.

231. Calibration of the failed-fuel-element detection systems in the Ågesta reactor. By O. Strindehag. 1966. 52 p. Sw. cr. 8:—.

232. Progress report 1965. Nuclear chemistry. Ed. by G. Carleson. 1966. 26 p. Sw. cr. 8:—.

233. A Summary Report on Assembly 3 of FR0. By T. L. Andersson, B. Brunfelter, P. F. Cecchi, E. Hellstrand, J. Kockum, S-O. Londen and L. I. Tirén. 1966. 34 p. Sw. cr. 8:—.

234. Recipient capacity of Tvären, a Baltic Bay. By P.-O. Agnedal and S. O. W. Bergström. 21 p. Sw. cr. 8:—

Förteckning över publicerade AES-rapporter

1. Analys medelst gamma-spektrometri. Av D. Brune. 1961. 10 s. Kr 6:—.
2. Bestrålningsförändringar och neutronatmosfär i reaktortrycktankar — några synpunkter. Av M. Grounes. 1962. 33 s. Kr 6:—.
3. Studium av sträckgränsen i mjukt stål. Av G. Östberg och R. Attermo. 1963. 17 s. Kr 6:—.
4. Teknisk upphandling inom reaktarområdet. Av Erik Janson. 1963. 64 s. Kr 8:—.
5. Ågesta Kraftvärmeverk. Sammanställning av tekniska data, beskrivningar m. m. för reaktordelen. Av B. Lilliehöök. 1964. 336 s. Kr 15:—.
6. Atomdagen 1965. Sammanställning av föredrag och diskussioner. Av S. Sandström. 1966. 321 s. Kr 15:—.

Additional copies available at the library af AB Atomenergi, Studsvik, Nyköping, Sweden. Transparent microcards af the reports are obtainable through the International Documentation Center, Tumba, Sweden.

EOS-tryckerierna, Stockholm 1966