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EFFECT OF HYPOIODOUS ACID VOLATILITY ON THE IODINE SOURCE TERM IN REACTOR ACCIDENTS

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Abstract

A FORTRAN code ACT WATCH has been developed to establish an improved understanding of essential radionuclide behaviour mechanisms, especially related to iodine chemistry, in reactor accidents. The accident scenarios calculated in this paper are based on the Loss of Coolant Accident at the Loviisa Nuclear Power Plant. The effect of different airborne iodine species, especially HIO, on the iodine source term has been studied.

The main cause of the high HIO release in the system modelled is the increase of I_2 hydrolysis rate along with the temperature increase, which accelerates HIO production. Due to the high radiation level near the reactor core, I_2 is produced from I^- very rapidly. High temperature in the reactor coolant causes I_2 to be transformed into HIO and through the boiling of the coolant volatile I_2 and HIO are transferred efficiently into the gas phase. High filtration efficiency for particulate iodine causes I^- release to be much lower than those of I_2 and HIO.

1. INTRODUCTION

In reactor accidents iodine in the reactor core may be released into the reactor containment. In some accident scenarios release of iodine can cause significant radiation doses. Therefore iodine behaviour in the containment must be known well enough to make reasonable predictions on the doses resulting from the iodine release, as well as to do decisions of severe accident management measures or emergency preparedness actions.

Since in many accident scenarios the main release path is through the gas phase of the reactor containment, it is important to understand the formation of different iodine species and their transfer between gas and aqueous phases, as well as the conditions affecting these phenomena.

The airborne iodine species that are considered here are iodine (I_2) and hypiodous acid (HIO), which are volatile, and iodide (I^-) as aerosol. Originally in the reactor core almost all of the iodine is of the form of cesium iodide (CsI), which dissolves into Cs^+ and I^- in water solutions. This species may react with reaction products from radiolysis of water producing I_2 .

HIO is an interesting species, since the hydrolysis of I_2 in water produces HIO. Also the filter retention factor of HIO may differ from that of I_2 . It seems that if HIO is transferred from the water phase to the gas phase and remains stable as indicated in some references, the main iodine species of the release from the plant can be HIO.

2. CALCULATION PROGRAMME DESCRIPTION

ACT WATCH (A Program for Activity Release Calculations Including Water Chemistry and Spray Droplets) was developed at IVO International Ltd to introduce an improved understanding of essential radionuclide behaviour mechanisms, especially related to iodine chemistry, in reactor accidents. Some traditional methods for estimating iodine releases may be too coarse to justify any specific statement on iodine doses. With ACT WATCH it is possible to estimate both the total behaviour of iodine and the relative significance of various chemical forms, as well as of factors influencing these, such as pH-value.

2.1 Compartment Structure

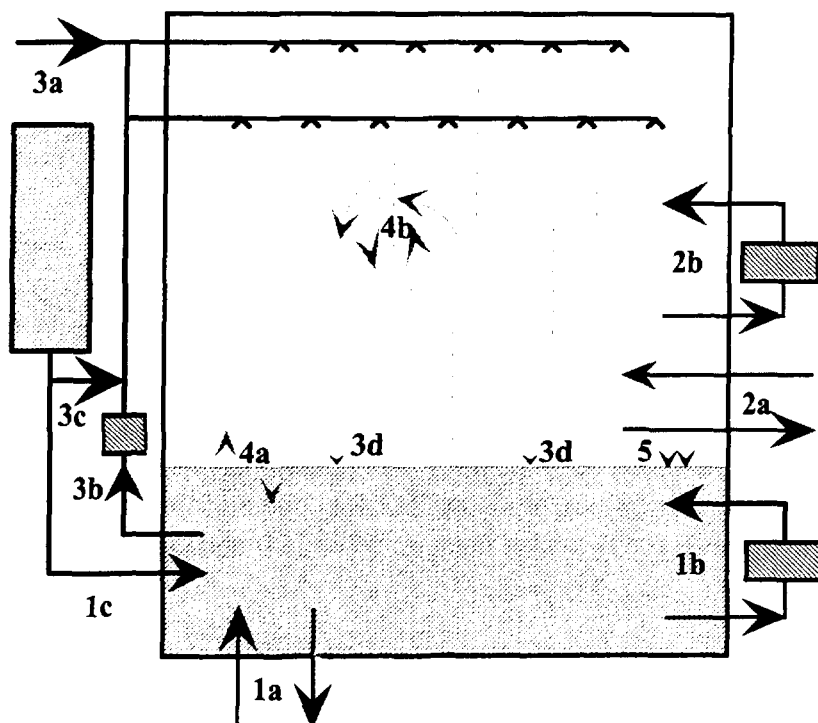
ACT WATCH divides the whole system into smaller compartments which are treated separately. Each compartment can contain a gas volume, a water volume and a spray system, in which ten groups of droplet sizes are allowed. One such compartment is presented in Fig. 1. At present ACT WATCH can handle up to nine of these compartments.

Gas flows between different compartments (2a) and gas circulation through filters do not affect the compartment volumes, but volume changes are caused by water flows assuming the total volume of a compartment to remain unchanged. Spray droplets in the gas are not carried along the flowing gas and they affect volumes only by falling into the water volume (3d).

Water flows include flows between compartments (1a), circulation through filters (1b) and flow from the emergency coolant system. Also water injection to the spray system from other compartments (3a), from the same compartment (3b), from the emergency coolant system and

the spray droplets falling to the water volume (3d) are treated as water flows. The flows between different compartments can be filtered, as well.

Figure 1. Flow Scheme for a Single Compartment



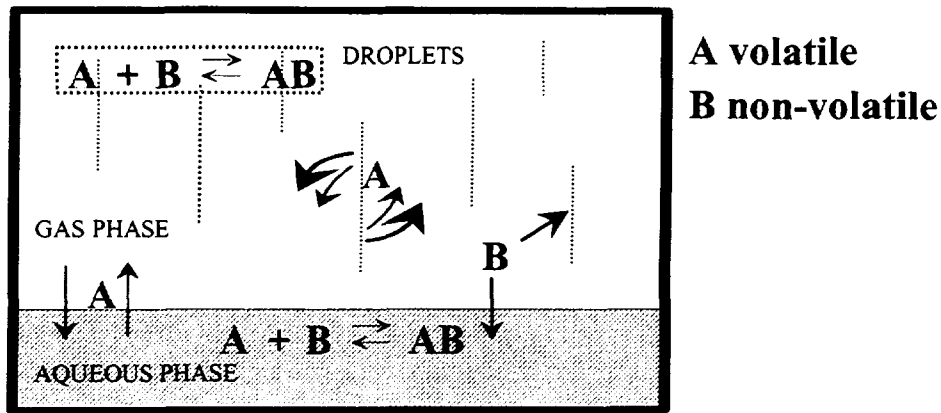
In addition to flows chemical compounds can be transferred between water and gas volumes (4a) and between gas and spray droplets (4b). Melting of ice in an ice-condenser (5) transfers the compounds trapped in the ice-condenser to water volume together with the flowing water.

Water and gas flows can also be directed out of the system examined. In this case they are treated as releases. At maximum there can be three releases in ACT WATCH, and both gas and water flows can be directed to the same release.

2.2 Chemical Environment

The chemical environment to be considered is presented in Fig. 2. Chemical reactions are assumed to take place in water phases, including the spray droplets. Only the volatile compounds (A) can be transferred from water to gas. Not only the volatile compounds, but also aerosol particles (initially released into the gas phase) can be transferred from gas to water.

There can be up to 15 different compounds and 50 reactions in ACT WATCH defined by user. The reaction rate of a specified reaction is assumed to be proportional to the concentrations of the compounds participating in the reaction. The reaction constant in one direction of a reaction is fixed, but in the reverse direction it is temperature dependent. This causes the equilibrium of the reactions to be dependent of the temperature of the solution.

Figure 2. Chemical Environment Considered

Boric acid (H_3BO_3), hydrazine (N_2H_4) and potassium hydroxide (KOH) can be added to control the pH-value of the solution. N_2H_4 is assumed to be thermally decomposed into ammonia (NH_3). Calculating the pH-value these compounds are assumed to be in the equilibrium concentrations with their decomposition products. The ice condenser ice contains sodium tetraborate (or borax, $Na_2B_4O_7 \cdot 10 H_2O$), which must be taken into account as a proper combination of H_3BO_3 and KOH.

ACT WATCH has a possibility to define radiation induced chemical decomposition reactions, where one compound decomposes into several other compounds. Reaction rate in this kind of reaction depends on the concentration of the compound decomposing and the radiation dose rate in the water solution.

2.3 Mass Transfer

Mass transfer of volatile compounds between water solution and gas is induced by the partition phenomenon. The mass transfer coefficient from water to gas is constant, but the partition coefficient is a function of temperature and can be defined separately for each compound examined.

The spray system can include at maximum ten groups of droplets with different droplet diameters. Compared with water pools spray droplets are very efficient in transferring volatile compounds to or from gas, because of their large surface area to volume ratio.

Spray droplets also wash aerosol particles from gas. Impaction, interception and diffusion are taken into account, when the particle collection efficiency is calculated for the droplets.

Aerosol particles are considered to have a constant particle size distribution. They can be released to gas volumes directly from fuel. In addition to being collected by the spray droplets they are transferred to water volumes or on the compartment floors by gravitational settling.

2.4 Activities

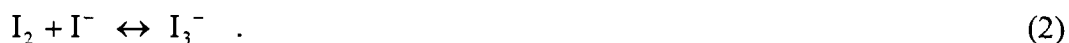
Different radionuclides are carried by the compounds containing the same element, to which the nuclide belongs. However, the activities are calculated at the same time as the chemical effects. This is because the different sources of the nuclide, e.g. precursors, affect the activities in such way that the activity calculations cannot be treated separately.

3. IODINE CHEMISTRY

One of the main reactions describing the iodine behaviour in the water solute is iodine (I_2) hydrolysis into hypoiodous acid (HIO) and iodide (I^-):



I_2 and I^- may associate and produce tri-iodide (I_3^-):

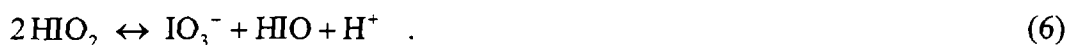
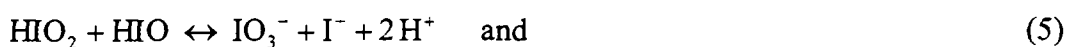


HIO dissociates in water to form hypoiodite (IO^-):



The reaction equilibrium of (1) shifts to the right and of (2) to the left with increasing temperature. The equilibrium constant of (3) is not affected so much by temperature changes.

Also reactions between HIO molecules may produce iodous acid (HIO_2) and iodate (IO_3^-) through following reactions [Edelson and Noyes 1979; Clough and Starkie 1985; Gorbovitskaya et al. 1993].



Often the net reaction of (4) and (5) or (4) and (6) is considered [e.g. Furrer et al. 1989; Kupferschmidt et al. 1992], but in this study the reactions are treated as separate, because of the interest in HIO behaviour.

Also HIO reduction through a reaction with IO^- is taken into account [Gorbovitskaya et al. 1993]:



Iodide oxidation by radiolysis is considered as [Furrer et al. 1989]:



where $h\nu$ is the absorbed energy into water from radiation. Furrer et al. [1989] consider also the backward reaction of (8), but since it is very slow compared to (1), it is not taken into account in this study. In this model the reaction rate (r) of (8) is fixed to fit the rate given by Furrer et al. [1989] ($r \propto [H^{+}]^{0.25}$) at pH-level 7.

Reaction (8) is very rapid compared to oxidation by dissolved oxygen [Bell et al. 1982; Furrer et al. 1989]:



which therefore has only a minor importance. Nevertheless, reaction (9) is considered in the model.

Volatile iodine species may transfer between aqueous and gas phases by partitioning through the boundary layer of the phases. The volatile compounds taken into account in this study are I_2 and HIO. Partition coefficients for these species as a function of temperature are fitted to the data given by Furrer et al. [1985]. These partitioning characteristics for HIO are referred here as **High HIO Volatility**, which is the base case to be studied.

Also two other HIO volatilities are considered. In one of these cases HIO is less volatile than in **High HIO Volatility** at high temperatures [Lin 1992], and therefore it is referred as **Low HIO Volatility**. In another case the HIO is assumed to be non-volatile and the case is called as **HIO Non-Volatile**.

4. ACCIDENT DESCRIPTION

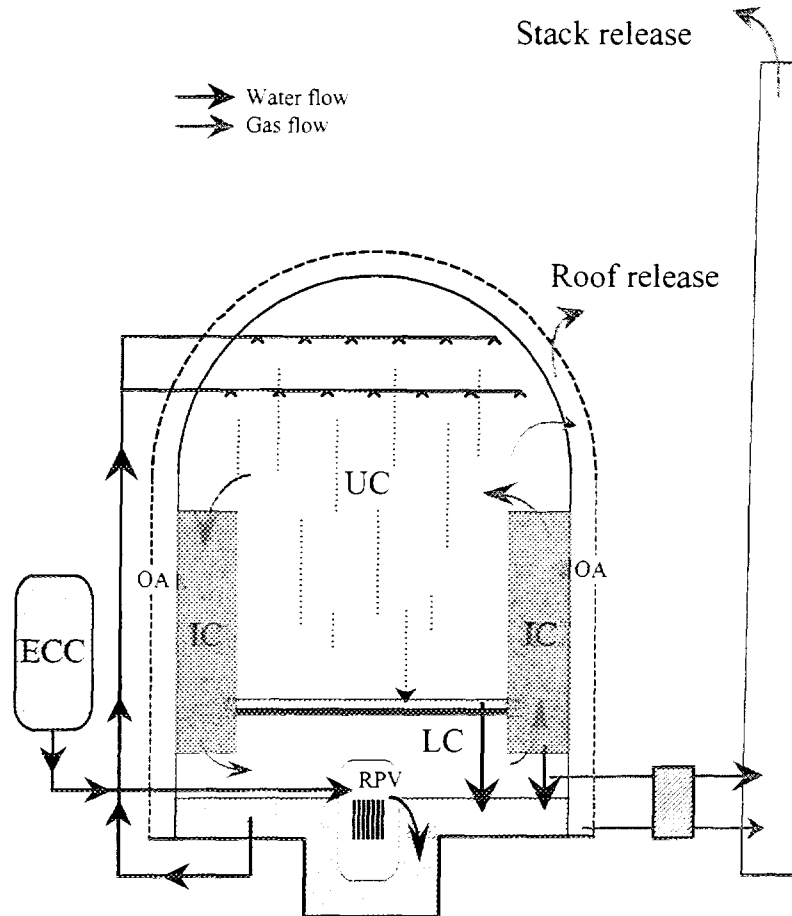
The Loviisa Nuclear Power Plant (NPP) is a VVER-440 type model 213 PWR with an ice condenser containment. A schematic drawing of the Loviisa containment is shown in Fig. 3. The accident scenarios calculated are based on the Loss of Coolant Accident (LOCA), which is used as a Design Basis Accident (DBA) at the Loviisa NPP. In these scenarios the release from the reactor pressure vessel (RPV) goes through primary circuit into the steam generator room. The steam generator room is here denoted as lower compartment (LC) of the containment. When steam is purged into the lower compartment it penetrates through ice condensers (IC) into the upper compartment (UC), which is the main volume of the containment. The ice melted by the condensing steam drains into the LC.

Due to the pressurization of the containment there is leakage from the UC into the outer annulus (OA), which leaks further into the environment. This leakage is here denoted as Roof Release, although the release may take place at a much lower height level than from the roof of the station.

Both the LC and OA are ventilated, and the gas flows through filters into the stack. However, the ventilation from the LC is assumed to be stopped at 5 s. Until this point of time there is no

release from the reactor core, and therefore the ventilation of the LC has no effect on the releases from the station.

Figure 3. Scheme of the Flow System Considered



Emergency core coolant (ECC) is pumped both into the RPV and into the spray system of the UC. After the emergency coolant has run out from the ECC tanks the core coolant is pumped from the LC sumps. The water on the UC floor from the fallen spray droplets is drained into the LC sumps.

The volumes and cross sectional areas of the compartments are given in Table 1. The cross section of the core region effects nothing, so it is arbitrary.

Table 1. Volumes and Cross Sections of the Compartments

Compartment	Core region	Boil. vol	LC	UC	OA
Total volume (m ³)	15.6	14.2	6 396	46 881	20 692
Water volume (m ³)	15.6	1	230	0	0
Cross section (m ²)	1	10 ⁶	966	1 320	150

The gas flow rate from the LC to UC raises to $2000 \text{ m}^3/\text{s}$ in 5 seconds and after that decreases rather quickly to reach $5 \text{ m}^3/\text{s}$ at 150 s. From the UC to the OA the flow rate is around $1 \text{ dm}^3/\text{s}$ throughout the calculation, which corresponds to a relative leakage of 0.2 % per day. The outer annulus leaks into the environment at a rate about $1 \text{ m}^3/\text{s}$ until 1000 seconds and at a rate about $0.2 \text{ m}^3/\text{s}$ between about 5000 and 6000 seconds. The ventilation flow rate from the OA to the stack is $0.69 \text{ m}^3/\text{s}$ throughout the calculation.

Water injection into the RPV is $33 \text{ dm}^3/\text{s}$ during 20 to 70 seconds and $137 \text{ dm}^3/\text{s}$ after that. Flow rate into the spray system is $200 \text{ dm}^3/\text{s}$ starting at 60 s. This flow rate corresponds to one operable spray water pump. Until 2460 s the injection of water comes from the ECC tanks, and after that from the sump water in the LC. The spray water fallen on the UC floor starts to drain into the LC at 950 s.

The temperatures in the core region and in the boiling volume are assumed to be $105 \text{ }^\circ\text{C}$. Temperature in the LC is $90 \text{ }^\circ\text{C}$ and in the OA $30 \text{ }^\circ\text{C}$. The the initial temperature of the UC is $45 \text{ }^\circ\text{C}$, but after switching to the sump water recirculation the spray water temperature increases, and therefore the temperature raises to $60 \text{ }^\circ\text{C}$.

At shutdown there is around 45 moles of iodine and $1.32 \cdot 10^{18} \text{ Bq}$ of ^{131}I in the reactor core. 2.2 % of these is assumed to be in the fuel gaps, and this amount is released from the fuel during the accident. The fuel reaches its maximum temperature at 5 s, and 10 % of the gap inventory of iodine is bursted as I^- -aerosols into the LC gas phase. The rest of the gap inventory leaks into the core region water between 300 and 3600 seconds as I^- . The core temperature analyses for the LOCA show, that the fuel cladding temperature does not exceed the cladding rupture limit, so the gap release as expressed above is completely hypothetical.

The radiation level in the core region water is very high, ranging from 700 Gy/s at shutdown to 15 Gy/s at 30 d. This dose rate corresponds to around 10 % of the decay heat to be absorbed as radiation into the core region water. The core region is the only compartment, in which the radiation is taken into account.

Boiling is assumed to occur until 1000 s, and at that time the coolant flows from the core region through 'Boiling volume'. In this compartment the gas to water volume ratio is 13.2 and the cross sectional area, that means also the interfacial area of the liquid and gas phases, is very large. These characteristics with the temperature of $105 \text{ }^\circ\text{C}$ cause 60 % of the I_2 in the aqueous phase to transfer into the gas phase.

The iodine release from fuel and I_2 distribution as formulated above are adapted from the CEC recommendations for LOCA calculations [1992].

The size of the aerosol particles in the gas phases is assumed to be $1 \text{ }\mu\text{m}$. This size has been chosen, because particles of this size have relatively low settling velocity and they are not collected very efficiently by the spray droplets. The spray system produces six droplet groups with diameters ranging from 1 to 5 mm. The volume fractions of the droplet groups are considered fixed at the outlet of the spray nozzles. These spray droplet characteristics are based on the measurements made with the nozzles used in the Loviisa NPP.

In the ice condensers there is originally 870,000 kg ice. The ice is assumed to be totally melted at 4000 s, which causes the second leakage period from the OA due to the pressure raise in

the containment. In reality the ice would be totally melted only after several hours. The collection efficiency for aerosol particles in the IC is assumed to be a linear function of the ice mass, and it diminishes from its initial value of 50 % to zero.

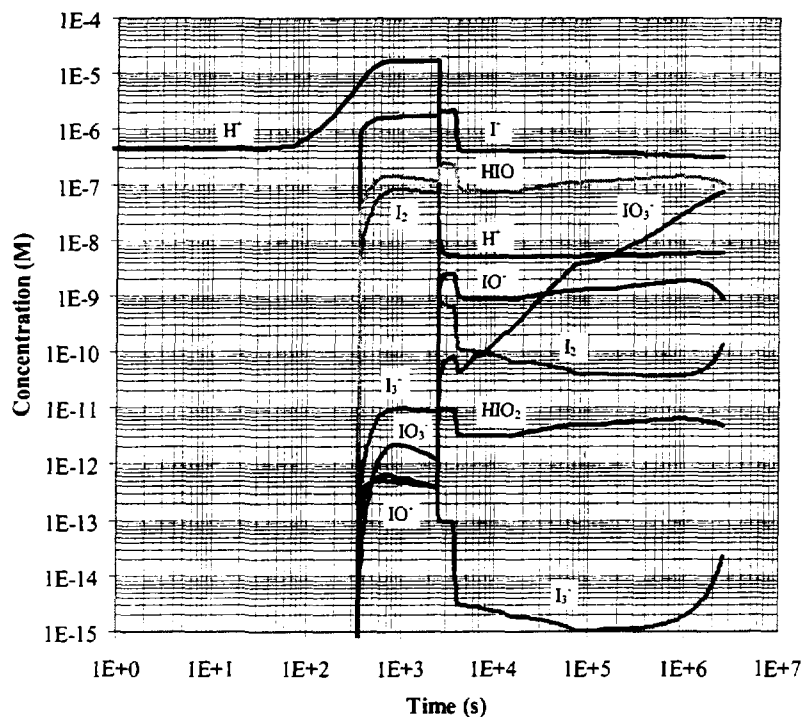
With the stack releases filtration efficiencies of 99.9 %, 90 % and 90 % are used for Γ , I_2 and HIO, respectively. The values are same for I_2 and HIO to make it easier to compare the releases of these two species.

5. RESULTS OF THE CALCULATIONS

The results for iodine species in the LOCA scenario presented in previous section with **High HIO Volatility** are shown in Figs. 4...10.

ECC is pumped into the RPV without pH-additives NH_3 and KOH . This can be seen from the relatively low pH-value of the core region water in the early stages of the calculation (Fig. 4). Although the water flow from the core region ends up into the LC (Fig. 5), the pH-value of the LC water is not very low. The melting ice from ICC contains large amounts of pH-additives (borax), which is the main reason for the higher pH-value. Also the lower temperature of the LC water compared to the core region water increases the pH-value a little. The assumption of pH-level 7 seems to overestimate the Γ oxidation by radiation in (8) after the recirculation of the sump water by a factor of about 2. Before the recirculation the radiolytic oxidation is underestimated by a factor of less than 4 at maximum.

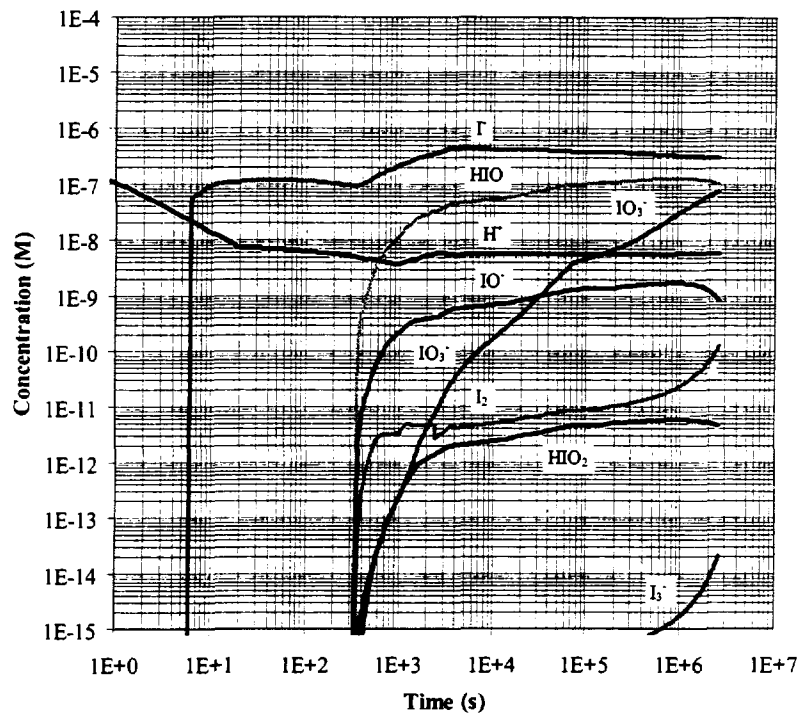
Figure 4. Concentrations in the Aqueous Phase of the Core Region



At 5 s there is a jump in the Γ -concentration in the LC gas phase (Fig. 6), and after that mainly the flow from the LC to the UC carries Γ away. Due to the aerosol particle collection efficiency of ice the melted ice draining down into the LC causes a rise in the concentration of the aqueous phase in the LC (Fig. 5). Part of the aerosol particles are, however, carried along the flow into the UC (Fig. 7).

Since radiolytic oxidation of Γ is assumed to take place only in the core region, Γ is the only iodine species in the aqueous phase in the LC water until iodine is introduced into the core region water at 300 s.

Figure 5. Concentrations in the Aqueous Phase of the Lower Compartment



At 300 s the second iodine release from the core starts, and the concentrations of iodine species in the core region water start to rise (Fig. 4). Boiling transfers the volatile I_2 and HIO rapidly into the gas phase of the LC (Fig. 6).

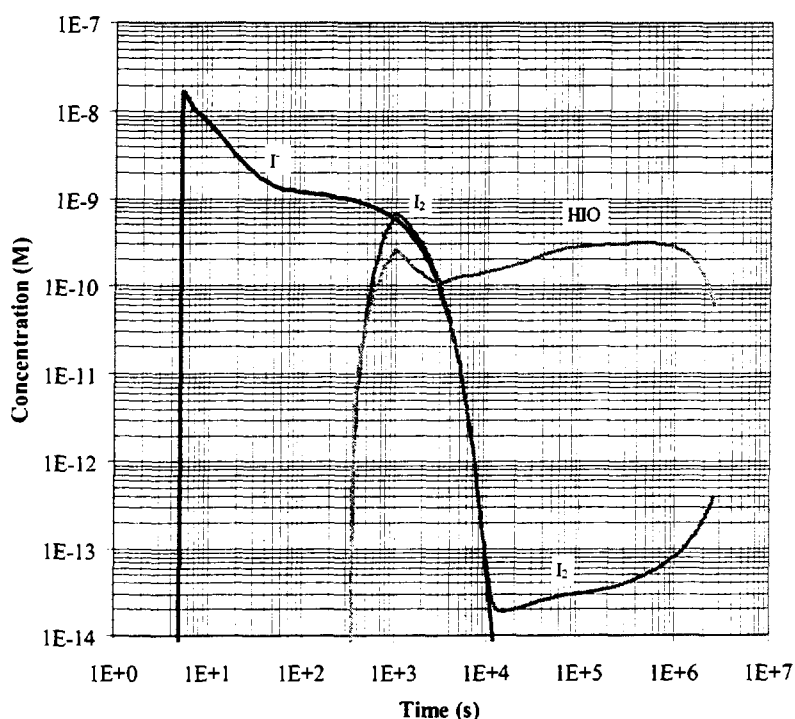
The pH-value in the core region water is rather low, while the ECC is being pumped into the core without KOH and N_2H_4 (Fig. 4). When the coolant flow from the LC sump into the core region starts, the pH-value in the core raises very quickly. This also affects strongly the concentrations of the iodine species.

The end of boiling at 1000 s is seen from the I_2 and HIO concentrations in the LC gas phase (Fig. 6). Till this point these concentrations have been increasing, but without the feeding from boiling they start to decrease. The HIO concentration, however, raises rather quickly again, which is due to the new equilibrium in the reactor core after switching to the sump water injection. Before this the pH is low and the I_2 and HIO concentration in the core are quite

similar (Fig. 4), but after the raise in the pH-value the I_2 concentration drops very rapidly. After a few hours HIO is the main iodine species in the LC gas phase.

During the boiling the I_2 concentration in the LC gas phase has raised far over the partition equilibrium (Fig. 6). Only after about 3 hours the concentration has reached such level that volatilization of I_2 from the LC aqueous phase exceeds the outflow from the LC gas phase. This increase in I_2 concentration can be seen later also from the UC and OA concentrations (Figs. 7 & 8).

Figure 6. Concentrations in the Gas Phase of the Lower Compartment



Looking at the concentrations in the UC gas phase (Fig. 7), it is interesting to see that the spray droplets cannot wash out I^- from the gas phase very efficiently. Actually, the I^- concentration is increasing slightly even the spray system is operating beginning at 60 s. Only after the I^- flow from the LC gas phase into the UC has dropped into relatively low level, the spray starts to reduce the I^- concentration in the UC gas phase.

Also an interesting phenomenon is the effect of the spray droplets on the concentrations of volatile iodine species after the spray is switched to take its water from the LC sump (Fig. 7). The effect on HIO is clearer than on I_2 , and there is a rapid increase of HIO concentration.

The concentrations in the OA remain quite low compared to the UC concentrations. This is due to the low leakage of the containment into the OA and quite effective ventilation of the OA.

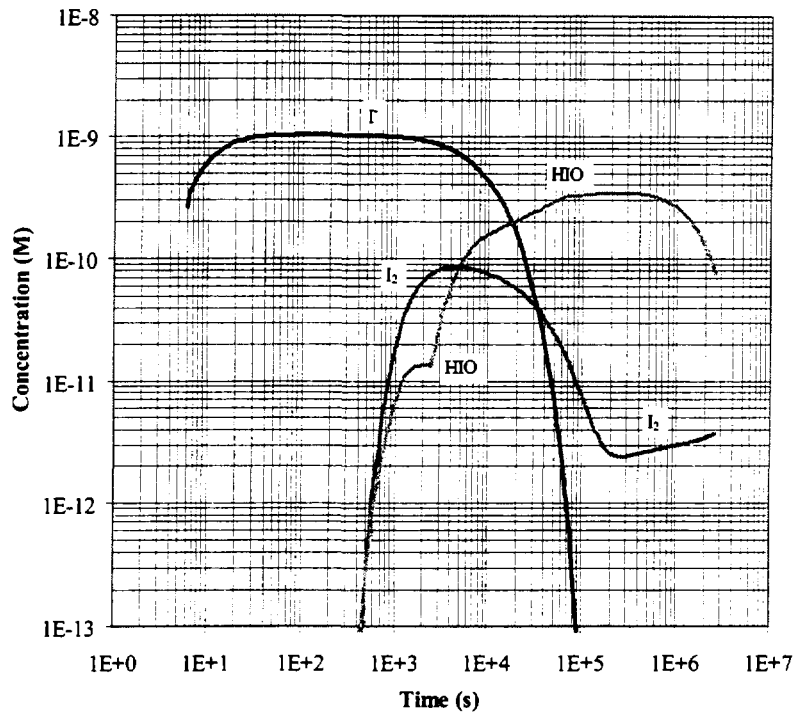
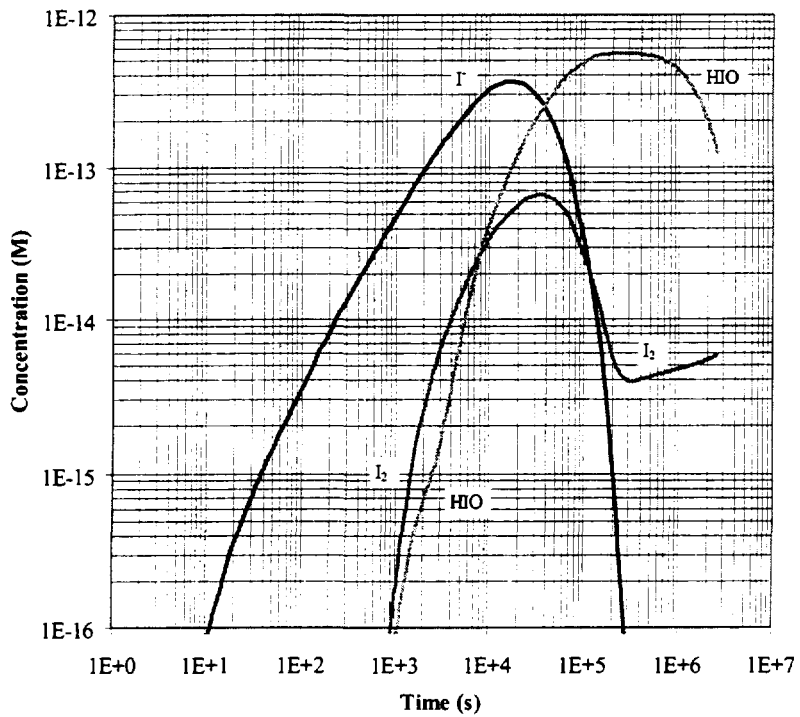
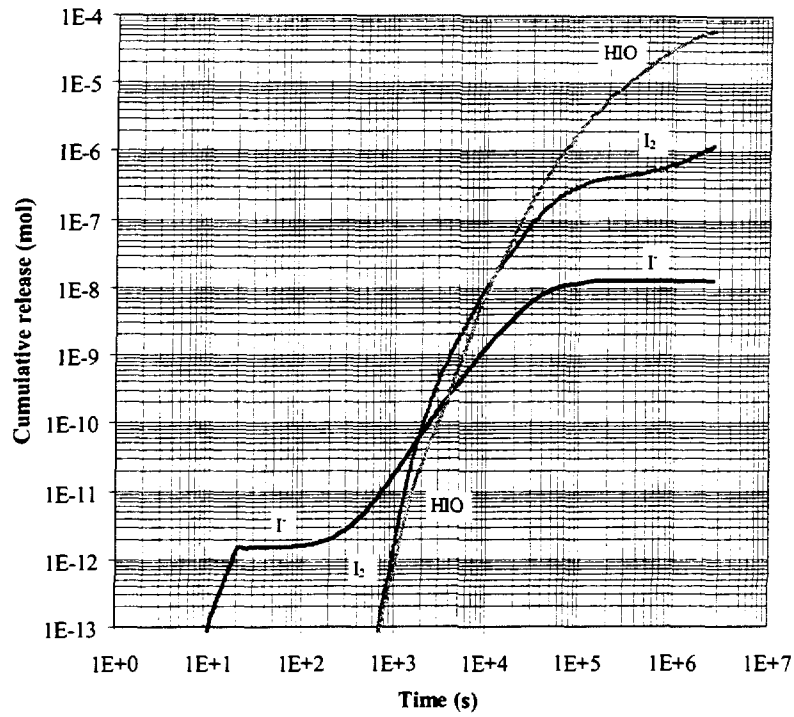
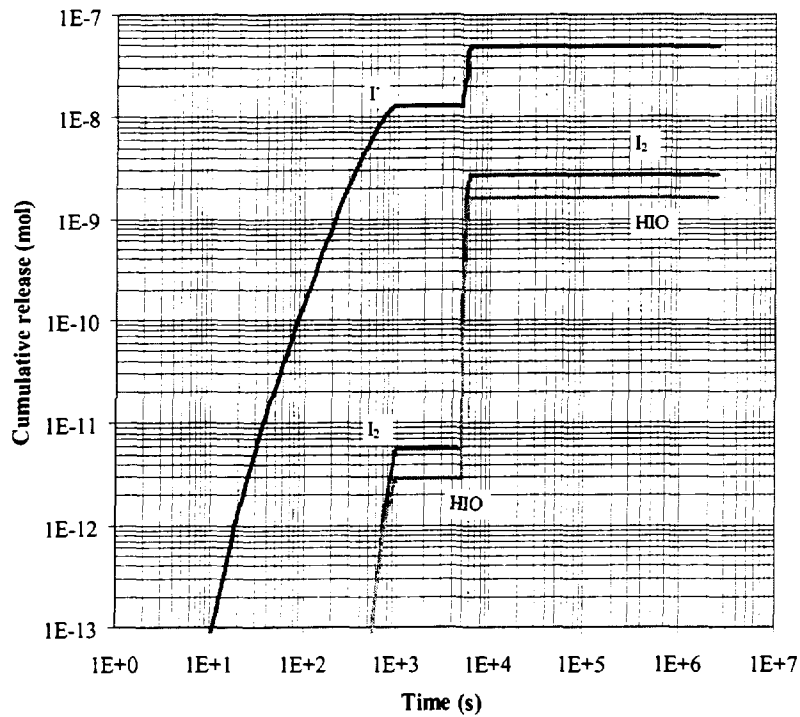
Figure 7. Concentrations in the Gas Phase of the Upper Compartment**Figure 8. Concentrations in the Gas Phase of the Outer Annulus**

Figure 9. Cumulative Release of Iodine Species from the Stack**Figure 10. Cumulative Release of Iodine Species from the Roof**

Considering the stack releases of different iodine species HIO becomes dominant after about 10 hours (Fig. 9). In the longer term HIO forms almost all of the iodine source term from the stack. I^- is only a minor part of the cumulative release, but this is partially due to the high filtration efficiency for this species.

For the roof releases (Fig. 10) the distribution between iodine species looks very different from those for stack releases. Because there is no filtration and the leakage stops before the volatile species are dominating in the gas phase of the UC, cumulative I_2 and HIO releases from the roof remain very low compared to the I^- release.

The activities of ^{131}I in different phases of compartments (Figs. 11 & 12) show also the total iodine distribution in the system.

The major part of the ^{131}I activity is in the LC water after the release from the core has stopped. From Fig. 11 the effect of spray can be seen by comparing the activity levels on the UC floor before the spray system started its operation at 60 s, and after that in the UC water. The spray droplets are far more efficient to reduce activity from UC gas phase than gravitational settling of the aerosol particles. However, spray system starts to transfer activity at a much higher rate after the spray water is taken from the LC sump.

Figure 11. ^{131}I Activity in the Aqueous Phases and on the Floors

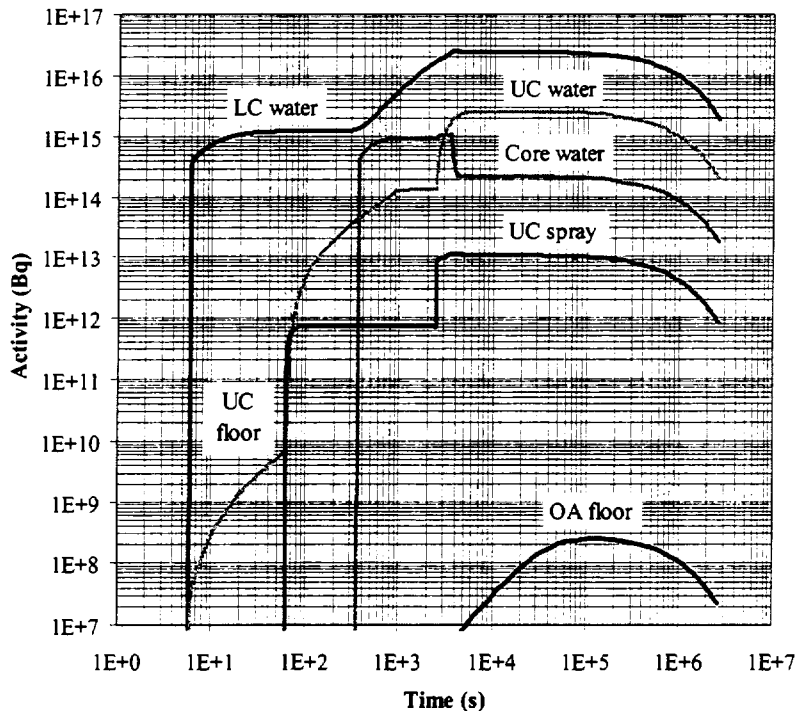


Figure 12. ¹³¹I Activity in the Gas Phases

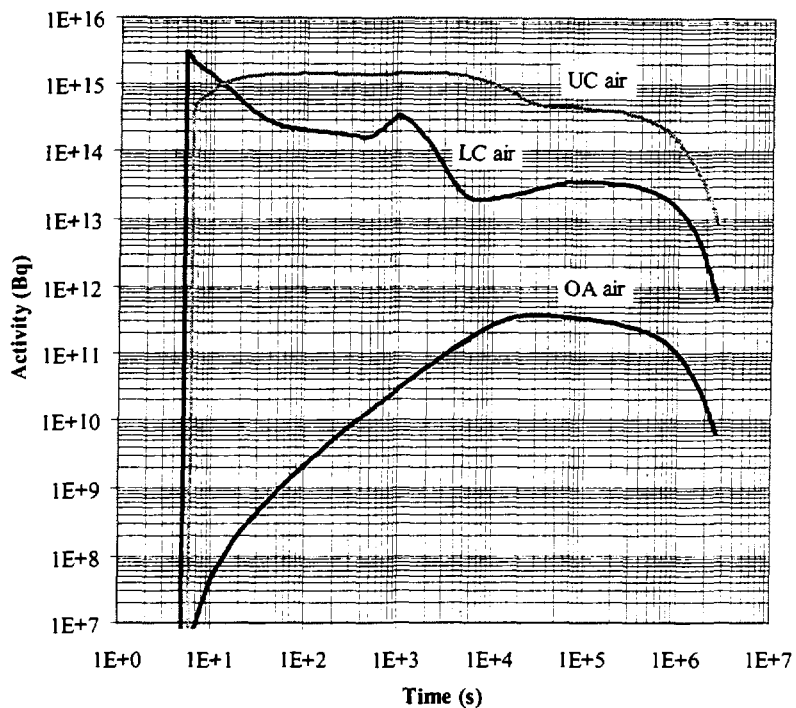


Figure 13. Cumulative Activity Release of ¹³¹I from the Station (High HIO Volatility)

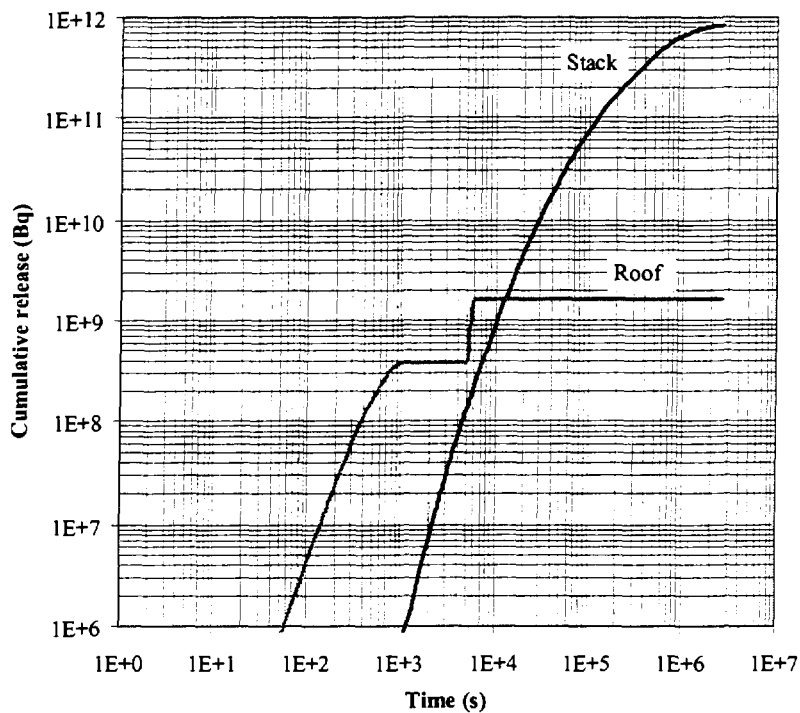
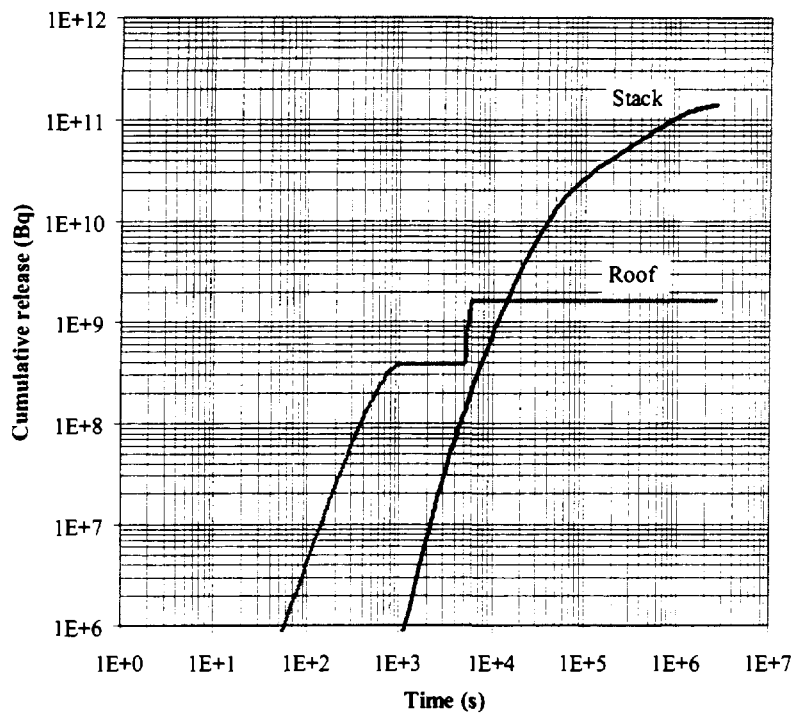


Fig. 13 shows the cumulative activity releases of ^{131}I from both the stack and the roof in the case High HIO Volatility. The total stack release is about 500 times the roof release.

The comparison of Low HIO Volatility case to High HIO Volatility case shows only small changes in the concentrations in the aqueous phases. The I_2 concentrations raise a little, which affects also the gas phase concentrations of I_2 . The total HIO release from the stack is only about 15 % of the release in the High HIO Volatility case. Also the roof release of HIO has dropped significantly.

The total effect of lower HIO volatility can be seen from the ^{131}I release (Fig. 14). As HIO is the dominating species of the stack release, the total ^{131}I release is less than 20 % of that in High HIO Volatility case. The roof release is formed almost exclusively by Γ , thus, it is not affected by the volatility of HIO.

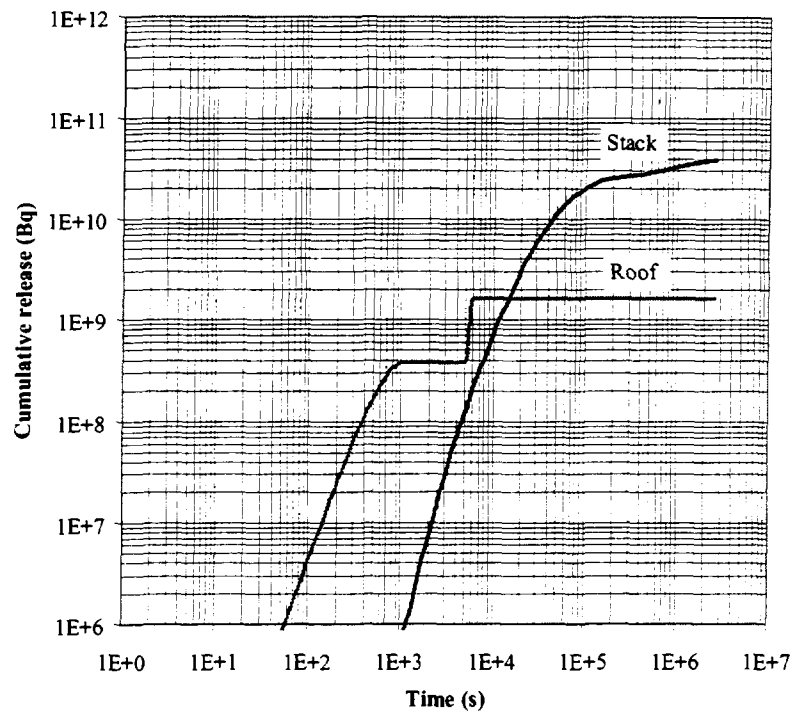
Figure 14. Cumulative Activity Release of ^{131}I from the Station (Low HIO Volatility)



The assumption of HIO being non-volatile has also very little effect on the concentrations in the aqueous phases. I_2 concentrations are about 10...20 % higher than in the case High HIO Volatility. This is also the effect on the I_2 concentrations in the gas phases.

The activity releases of ^{131}I for HIO Non-Volatile case are shown in Fig. 15. Compared to the results of the High HIO Volatility case the stack release starts to deviate around two hours. At 1 day, 7 days and 30 days the cumulative stack release remains around 30 %, 7 % and 5 %, respectively. The roof release is practically the same than in previous cases, since Γ is the dominant species for this release.

Figure 15. Cumulative Activity Release of ^{131}I from the Station (HIO Non-Volatile)



6. CONCLUSIONS

The main cause of the high HIO release in the system modelled is the increase of I_2 hydrolysis rate along with the temperature increase, which accelerates HIO production. Due to the high radiation level near the reactor core, I_2 is produced from I^- very rapidly. High temperature in the reactor coolant causes I_2 to be transformed into HIO and through the boiling of the coolant volatile I_2 and HIO are transferred efficiently into the gas phase.

In the chemical model considered the radiolytic oxidation of I^- into I_2 is assumed to be a linear function of dose rate. This assumption is made from experiments, which have been carried out at a rather low radiation level compared to the dose rate into the core region water. Therefore the radiolytic oxidation in this study may not be very reliable. The radiolysis of water and its affect on the iodide oxidation should be modelled in a more accurate way to improve understanding of the radiolytic oxidation of I^- . Furthermore, Furrer et al. [1989] have brought out that the reaction constant for the radiolytic oxidation (8) is overestimated in the absence of silver (Ag), and Loviisa NPP has no Ag in the reactor core.

Some references imply that HIO would not be significant species, due to its high partition coefficient [CEC 1992]. However, HIO partition coefficient decreases as temperature increases, and what is more important, the ratio of HIO and I_2 partition coefficients increases along with increasing temperature. Also, the hydrolysis of I_2 (1) becomes more efficient with high temperatures. Therefore, the relative significance of HIO seems to grow with increasing temperature.

Even if the HIO were not a stable species in the gas phase, it might have an effect on the iodine source term by transferring iodine into the gas phase, where HIO could be transformed into some more stable airborne iodine species.

The relative significance of volatile iodine species is probably not as high for conditions occurring in severe accidents than for e.g. LOCA scenarios considered here. During severe accidents the reactor core temperature is very high, and large amounts of fission products are released as aerosols from the core. Therefore the airborne fraction of the fission products is quite large compared to the LOCA scenarios.

In addition to the transfer parameters of different iodine species, there are also other factors affecting the release. The overall thermal hydraulic behaviour of the system may differ a lot from the scenario represented here. For example, different temperature and boiling assumptions may produce a result that shows other kind of iodine behaviour.

It must also be noted that the chemical model considered is quite simple, and only some of the various species and reactions are taken into account. The model needs to be improved, and one of main future work with ACT WATCH is to validate the code for the use it has been created for.

7. REFERENCES

Barton R.A. and Sims H.E. A Comparison of the Predictions of the INSPECT Reaction Set With Experimental Data. *Proceedings of the Third CSNI Workshop on Iodine Chemistry in Reactor Safety*, September 11-13 1991, Tokai-mura, Japan. p. 346-363.

Bell J.T.; Lietzke M.H. and Palmer D.A. Predicted rates of Formation of Iodine Hydrolysis Species at pH Levels, Concentrations and Temperatures Anticipated in LWR Accidents. Oak Ridge National laboratory, October 1982, 57 p. *NUREG/CR-2900*.

Clough P.N. and Starkie H.C. A Review of the Aqueous Chemistry and Partitioning of Inorganic Iodine Under LWR Severe Accident Conditions. *European Appl. Res. Rept. - Nucl. Sci. Technol.*, 1985, **6**, no. 4, p. 631-776. EUR 9408 EN.

Commission of the European Communities (CEC). *Nuclear Science and Technology, Realistic Methods for Calculating the Releases and Consequences of a Large LOCA*. 1992. EUR 14179 EN.

Edelson D. and Noyes R.M. Detailed Calculations modeling the Oscillatory Bray-Liebhafsky Reaction. *The Journal of Physical Chemistry*, 1979, **83**, no. 2, p. 212-220.

Furrer M.; Cripps R.C. and Gubler R. Measurement of the Iodine Partition Coefficient. *Nuclear Technology*, 1985, **70**, no. 2, p. 290-293.

Furrer M.; Cripps R.C. and Frick E. Iodine Severe Accident Behaviour Code IMPAIR 2. *PSI-Bericht Nr.25*, Januar 1989. 36 p.

Gorbovitskaya T.I.; Galinkin D.L.; Kants L.K.; Tiliks Yu.E.; Kotelkin I.M. and Luzanova L.M. Radiolysis of Dilute Aqueous Cesium Iodide Solutions. *Atomic Energy*, 1993, **74**, no. 5, p. 389-394.

Kupferschmidt W.C.H.; Buttazoni J.B.; Evans G.J.; Ford B.L.; Palson A.S.; Portman R. and Sanipelli G.G. Iodine Chemistry in the Presence of Vinyl Surfaces. *Proceedings of the Third CSNI Workshop on Iodine Chemistry in Reactor Safety*, September 11-13 1991, Tokai-mura, Japan. p. 213-229.

Lin C.C. Chemical Behavior of Radioiodine In Boiling Water Reactor Systems II: effects Hydrogen Water Chemistry. *Nuclear Technology*, 1992, **97**, no. 1, p. 71-78.