Due to large surface areas, the reaction of volatile, molecular iodine (I₂) with steel surfaces in the containment may play an important role in predicting the source term to the environment. Both wall retention of iodine and conversion of volatile into non-volatile iodine compounds at steel surfaces have to be considered. Two types of laboratory experiments were carried out at Siemens/KWU in order to investigate the reaction of I₂ at steel surfaces representative for German power plants.

1) For steel coupons submerged in an I₂ solution at T = 50°C, 90°C or 140°C the reaction rate of the I₂/I⁻ conversion was determined. No iodine loading was observed on the steel in the aqueous phase tests. I₂ reacts with the steel components (Fe, Cr or Ni) to form metal iodides on the surface which are all immediately dissolved in water under dissociation into the metal and the iodide ions. From these experiments, the I₂/I⁻ conversion rate constants over the temperature range 50°C - 140°C as well as the activation energy were determined. The measured data are suitable to be included in severe accident iodine codes such as IMPAIR.

2) Steel tubes were exposed to a steam/I₂ flow under dry air at T=120°C and steam-condensing conditions at T=120°C and 160°C. In dry air I₂ was retained on the steel surface and a deposition rate constant was measured. Under steam-condensing conditions there is an effective conversion of volatile I₂ to non-volatile I⁻ which is subsequently washed off from the steel surface. The I₂/I⁻ conversion rate constants suitable for modelling this process were determined. No temperature dependency was found in the range 120°C - 160°C.
1. INTRODUCTION

The knowledge of the chemical behaviour of radioiodine in the containment during a hypothetical core melt accident in a Light Water Reactor is essential for the prediction of the source term to the environment. The complex iodine chemistry is influenced by a variety of boundary conditions such as temperature, pH of sump(s) or radiation dose rate. Their effects have been investigated in the past or are currently under investigation. The results are implemented in codes modelling the kinetics of the various volatile and non-volatile iodine species in the containment during severe accidents. Due to large surface areas, the reaction of iodine with steel surfaces may also play an important role as regards either retention of iodine or conversion of volatile iodine compounds into non-volatile iodine compounds at surfaces.

Kinetic data are available in the literature for the deposition of elemental iodine ($I_2$) on steel surfaces in a dry atmosphere (e.g. air, steam) both under primary circuit and containment conditions. Other experiments described in the literature indicated qualitatively, that $I_2$ is effectively converted to $I^-$ on steel submerged in water or on steel surfaces covered by a water film due to steam-condensing conditions. No kinetic data had been measured for this $I_2/I^-$ conversion. The significance of this process is that through reduction of $I_2$ to $I^-$, volatile iodine is converted to non-volatile iodide. Other reactions in the iodine/steel system, e.g. hydrogen iodide + steel, may take place but do not have an impact on the oxidation state of the iodine species involved.

The present work provides so far lacking kinetic data for the reaction of iodine with steel surfaces which can be used for the modelling of iodine behaviour under severe accident containment conditions.
2. EXPERIMENTAL STUDY OF THE $\text{I}_2$/I$^-$ CONVERSION AT STEEL SURFACES IN THE AQUEOUS PHASE

2.1 Experimental

2.1.1 Tests at $T = 50^\circ\text{C}$ and $T = 90^\circ\text{C}$

Figure 1 shows the test setup used for the experiments performed at $50^\circ\text{C}$ and $90^\circ\text{C}$. A 120 mm ID x 200 mm cylindrical glass vessel is placed on a magnetic stirring hotplate (1). It's slightly convex glass cover is equipped with:

- A contact thermometer (2), tip encapsulated in glass, ensuring a constant temperature within ±1°C.
- The central fitting accommodates a 20 mm ID x 240 mm straight glass tube (3) followed by an activated charcoal filter (4); this prevents over-pressure in the vessel as well as uncontrolled release of radioactive iodine.
- A 2 mm ID glass tube (5) for sampling purposes.
- A separatory glass funnel (6) for dosing of iodine.

Two steel specimens (no. 7 in Fig. 1, each 100 mm x 50 mm x 1mm) are kept by a glass holder (8) so as not to interfere with the function of the glass coated stirrer at the bottom. The stirring ensures homogeneity of the solution in order to prevent mass transfer effects on the results.

Austenitic steel (component number 1.4541 or X10 CrNiTi 18 9) in the as-received state without further surface treatment as in German nuclear power plants was used. The steel coupons were only washed with acetone and water in an ultrasonic bath.

The aqueous phase has a volume of 1500 ml at the beginning of the test thus occupying about 64 % of the vessel volume. The pH is 2.4 adjusted by diluted sulfuric acid in order not to hydrolyze elemental iodine ($\text{I}_2$). No boric acid was present.

The tests are initiated by heating the aqueous phase and the submerged steel specimens, but yet without the elemental iodine, to the specified temperature. The starting point of the tests is the addition of a concentrated elemental iodine solution containing 1-131 tracer to reach a total concentration after dosing of about 1E-4 g-atom/l. Sampling may be performed at any desired time. Each sample has a volume of 10 ml.

2.1.2 Tests at $T = 140^\circ\text{C}$

The tests at $T = 140^\circ\text{C}$ were intended to be run under conditions as close to the lower temperature tests as possible. Due to the over-pressure, an autoclave is necessary and this has an impact on the setup (Figure 2) and the performance of the tests. A double-walled glass autoclave is used in order to avoid further steel surfaces other than the defined steel specimen. The iodine solution inside of a volume of up to 1 l is stirred magnetically (1). The inner reaction vessel is heated by an oil bath (2). The steel specimen (3) is suspended from the cover. A glass tube (4) serves for the dosing of the I-131 tracered iodine solution. Temperature (5) and pressure (7) are controlled. A security valve (7) would open at p > 10 bars. Charcoal filters are used for...
protection against unplanned iodine releases at various points of the apparatus. Samples are taken through the glass tube (9) by opening a valve.

An experiment is run by heating an aqueous solution (here pH = 1.5 to avoid I$_2$ hydrolysis) together with the inserted steel specimens. After having reached the preset temperature, the elemental iodine solution is dosed in. This two minute procedure defines the starting time of a test. Various samples can be collected and their amount is determined gravimetrically.

2.2 Analytical procedure

It is necessary to determine both the concentrations of elemental iodine (I$_2$) and iodide (I$^-$). Iodate through I$_2$ hydrolysis is not present in the solution as was checked. An ion-selective electrode sensitive to iodide, but not to iodate or elemental iodine, was used together with an Ag/AgCl reference electrode. The iodide electrode was calibrated in the concentration range 2E-6 mol/l to 4E-4 mol/l, the accuracy of the measurements is ± 10 %. First only the iodide concentration was determined in the liquid sample. Then, ascorbic acid was added to reduce the elemental iodine to iodide and the sum of both I$_2$ and I$^-$ concentrations was measured. Subtraction of both measurements yielded the I$_2$ concentration in the sample.

2.3 Evaluation of data

Elemental iodine reacts with steel under the formation of metal iodides, mainly iron iodide. These reaction products at the surface are immediately dissolved in the water phase (producing iodide ions) thereby leaving again a metallic surface for new I$_2$ attack. There is no iodine loading on the steel surface as was controlled with I-131. The net process is therefore the conversion of elemental, volatile iodine into water-soluble, non-volatile iodide. The rate constant for this I$_2$/I$^-$ conversion process would then simply be obtained by analyzing the increase of the iodide concentration as a function of time or alternatively by analyzing the decrease of the elemental iodine concentration as a function of time.

In practice, there are disturbing processes in the experimental setup. I$_2$ itself can be volatilized and it was found to be also converted to I$^-$ by a further process, presumably a glass surface as reported in [1]. All processes in the reaction vessel are depicted in Figure 3. The effects of the two disturbing processes on the I$_2$/I$^-$ conversion rate can be removed by performing blind tests under the same conditions, but without steel coupons. The mathematical treatment of the kinetics equations assuming first order reactions concerning the iodine species is straightforward and therefore not presented here. The solution is firstly an exponential decrease of the I$_2$ concentration in the aqueous phase as function of time and secondly, a build-up of iodide in the aqueous phase:

$$[I_2] = [I_2]_w \cdot \exp (-k_S t) \quad (1)$$

with $k_S = k_1 + k_u (S/V)_{Glass} + k_{55} (S/V)_{Steel}$

$k_1$, $k_u$, $k_{55}$: first order rate constants according to Figure 3
S: surface area
V: Volume of aqueous phase

\[ [I^-] = 2 \cdot [I_{2,0}]_w \cdot (k_u (S/V)^{Glass} + k_{55} (S/V)_{Steel}) / k_\Sigma (1 - \exp(-k_\Sigma t)) \]  \hspace{1cm} (2)

The rate constants \( k_1 \) and \( k_u \) were determined from experiments without steel samples. The overall reaction rate \( k_\Sigma \) was determined from the decrease of the \( I_2 \) concentration with time. Plotting the \( I^- \) concentration versus the transformed time-scale \( \chi(I^-) = 1 - \exp(-k_\Sigma t) \) yields a linear relationship from which the desired rate constant \( k_{55} \) results.

### 2.4 Results

Besides a number of pretests in order to optimize the analytical procedure and the performance of the tests, four pairs of main test (including steel coupons) / blind test (without steel coupons) were carried out: one pair at \( T = 50^\circ C \), one at \( 90^\circ C \) and two at \( 140^\circ C \).

The above equations are the basis for the analysis of the experimental data with a typical example for the \( I_2/I^- \) conversion process on steel shown in Figure 4. The upper part is the time dependency of the \( I_2 \) concentration in the aqueous phase at \( T = 90^\circ C \), the lower part shows the \( I^- \) concentrations in the same test. No error bars are displayed in this Figure, but the accuracy of the data points is estimated within 10 to 50 \%, with the better accuracy at the higher concentrations. Straight lines were fitted reasonably well to the data according to the modelling concept described in section 2.3. The corresponding blind test under the same boundary conditions is shown in Figure 5. The blind test also reveals a substantial \( I_2/I^- \) conversion presumably due to the glass surface. The slopes of the four curves shown as well as the offsets of the \( I_2 \) curves are needed according to the above model. This yielded the constants \( k_\Sigma, [I_{2,0}], k_1 \) and \( k_u \) in the blind and in the main test, from which \( k_{55} \) can be determined.

The rate constant for the conversion on steel surfaces derived from these two experiments at \( 90^\circ C \) is \( k_{55} = (7.5 \pm 2.2) \times 10^{-7} \) m/s. The error contains all statistical errors of the above mentioned parameters. Analogously, at \( T = 50^\circ C \) \( k_{55} = (2.8 \pm 0.3) \times 10^{-8} \) m/s. At \( T = 140^\circ C \), only one upper and one lower limit for the rate constant were determined due to limitations in the test apparatus and in the performance. But these two measurements define a reasonable range of validity of the rate constant at that temperature, \( 1.3 \times 10^{-5} \) m/s \( \leq k_{55} \leq 3.3 \times 10^{-5} \) m/s.

The temperature dependency of the conversion rate constant is shown in the Arrhenius plot of Figure 6. From the slope of the fit to the data points in Figure 6 the activation energy \( E_a = 8.1 \times 10^4 \) J/mol of the \( I_2/I^- \) conversion is deduced.

### 2.5 Discussion and conclusions

The experimental program to the system \( I_2/steel \) in aqueous solution can be summarized as follows: \( I_2 \) is effectively reduced by steel surfaces to \( I^- \). There is no net iodine deposition on the steel surface. The rate constants between \( T = 50^\circ C \) and \( T = 140^\circ C \), thereby covering the relevant
severe accident temperature range, were measured. They are suited to the steel types and surfaces as used in German plants. Therefore, there was no need for the determination of surface roughnesses in this work. On the other side, it is known from I₂ deposition on steel surfaces in the gas phase that surface roughnesses influence the deposition rate constants significantly [2].

No kinetic data existed in the literature so far, but the measurements in this work are compatible with qualitative observations also in aqueous solutions reported in [1] and in [2].

The observation of zero iodine deposition on the steel surface is important for the modelling of the I₂/I⁻ conversion in severe accident iodine codes such as IMPAIR [3]. This means, that the surface area is constant over time and that the reaction is of first order concerning the I₂ concentration:

\[
\frac{d[I^-]}{dt} = -2 \frac{d[I_2]}{dt} = 2 k_{55} \frac{S}{V} [I_2]
\]

3. EXPERIMENTAL STUDY OF THE IODINE/STEEL REACTIONS IN THE GAS PHASE

3.1 Experimental

The experimental setup to examine the I₂/steel reaction in the gaseous phase at \( T = 120^\circ C \) and \( T = 160^\circ C \) is shown in Figure 7. It consists mainly of three units:

- Central unit with
  - steel specimen (tube)
  - gas inlet and outlet
  - vessel sampling recondensed steam from the tube
- Supporting unit with
  - steam generator
  - steam overheating to avoid steam condensation in front of the steel tube
  - provision for laboratory gas, cleaning and overheating
  - I₂ dosing unit
- Sampling unit with three parallel gas filters to discriminate
  - aerosols
  - I₂ (with DSM 11, KI-impregnated silica gel)
  - I₂ + Organic iodides (with AC6120, AgNO₃-impregnated silica gel)

The steel tube has a 70 mm inner diameter and a 160 mm length. The material has the specification 1.4541 like the one already described in section 2.

This apparatus has also been used in numerous other iodine experiments. Three tests were therefore performed. The boundary conditions are summarized in the Table 1.

I₂ tracered with I-131 was led through the steel tube either in dry air or in condensing steam for three hours. The preset steam condensation rates in the tests 2 and 3 were controled by the
pressure in the system. Steam that had condensed on the vertical steel tube flowed down and was collected in a condensate vessel.

After the test the steel tube and the filters were removed and their iodine loadings were measured by γ-counting of the I-131 tracer.

The condensed steam in the tests 2 and 3 was analyzed with respect to its iodine content (γ-counting) and with respect to the chemical forms of the iodine, namely I₂, I⁻ and IO₃⁻. The latter was performed due to the fact that the elemental iodine led into the test apparatus can in principle enter the condensate vessel by two different paths: either directly with the condensing steam or after having reacted with the steel surface to the metal iodide, which would be washed off from the steel tube surface. These two paths can be distinguished since the "metal iodide path" does not produce iodate whereas this would be the case with the "direct path" through the well-known I₂ hydrolysis in the neutral condensed water. A chemical separation of the iodine species in the condensed water essentially according to [4] was therefore performed. Besides, the iodide-sensitive electrode was used to discriminate I₂ and I⁻.

Only one test was performed under dry conditions (test 1) because the influence of temperature or surface roughness had already been examined using the rather similar stainless steel 304 by [2].

3.2 Evaluation of data

It is the aim of the present experiments to determine the rate constants of the I₂/I⁻ conversion and of the iodine deposition. The following picture serves as a basis for the modelling of the data:
- Gasborne I₂ reacts with steel to form metal iodides.
- Under dry conditions these metal iodides remain on the surface, whereas not converted elemental iodine should desorb again under the chosen temperatures.
- Under steam condensing conditions the metal iodides are washed off from the surface and enter the condensate vessel (confirmed by pretests).

The primary step of the I₂/I⁻ conversion is the deposition of I₂ on steel. The increase of the iodine surface loading is

\[
\frac{d[I₂]_s}{dt} = + k_D \cdot [I₂]
\]

This is simplified for small depositions as is the case in the current experiments:

\[
\frac{d[I₂]_s}{dt} \equiv \Delta [I₂]_s / \Delta t
\]

\[
\Delta [I₂]_s \quad \text{change in iodine surface loading}
\]

\[
\Delta t \quad \text{test duration}
\]

From this follows for the deposition rate constant k_D:

\[
k_D \equiv \Delta [I₂]_s / (\Delta t \cdot 1/2 \cdot ([I₂]_a + [I₂]_e))
\]
with the I\(_2\) concentration in the gas phase entering the steel tube ([I\(_2\)]\(_a\)) and the I\(_2\) concentration in the gas phase leaving the steel tube ([I\(_2\)]\(_e\)). In the test with dry air [I\(_2\)]\(_e\) is given by the iodine measured in the filter after the steel tube. [I\(_2\)]\(_a\) is the sum of deposited iodine and the iodine on the filter. It shall be added that iodine retained on surfaces of sample lines etc. was measured in all experiments and included in the data evaluation.

The following data evaluation with respect to I\(_2\)/I\(^{-}\) conversion rate constant \(k_{K}\) the takes into account that the reaction of I\(_2\) with steel is limited to a "contact time" \(\tau\) in the flowing system. The decrease of I\(_2\) due to formation of I\(^{-}\) is:

\[
\frac{d [I_2]}{dt} = - k_K \cdot \left(\frac{S}{V}\right) \cdot [I_2] \tag{7}
\]

The rate constant is obtained by integration within the limits 0 to \(\tau\) and [I\(_2\)]\(_a\) to [I\(_2\)]\(_e\):

\[
k_K = \left(\frac{V}{(S \cdot \tau)}\right) \cdot \ln\left(\frac{[I_2]_a}{[I_2]_e}\right) \tag{8}
\]

[I\(_2\)]\(_a\) and [I\(_2\)]\(_e\) are defined as in equation 6. In the tests with a steam condensing atmosphere there is an effective wash-off from the steel surface into the condensate vessel. This iodine amount is included into the quantity [I\(_2\)]\(_a\).

As the results in tests 2 and 3 depend on the condensation rates of the steam, condensation rates as expected in severe accidents were chosen (see Table 1).

3.3 Results

The results in the three tests carried out are summarized in Table 2.

Test 1 (dry air conditions) yielded a deposition rate constant of \(k_D = 6.3 \times 10^{-5}\) m/s. This is to be compared with \(k_D = 6.5 \times 10^{-4}\) m/s taken from [2] at the same temperature of 120°C. The difference of one order of magnitude may be caused by different reasons:
- the Rosenberg tests were carried out with overheated steam instead of air,
- the surface roughness, which was not determined in the present experiments, could be different,
- mass transfer effects (diffusion to the surface).

Test 2 (steam condensing conditions) showed, that the iodine is either transported to the condensate vessel or further downstream to the filter. The amount of iodine on the surface is very small and would be completely washed off in case of further steam condensing without iodine inlet. In addition, the analysis of the condensed water revealed no iodate thereby indicating that no elemental iodine had entered the condensate vessel and that only metal iodides had been transported to this vessel.

The I\(_2\)/I\(^{-}\) conversion is much faster than the I\(_2\) deposition at the same temperature under dry air conditions (see Table 2). This can be explained by a rapid revolatilization of I\(_2\) under dry air conditions before it reacts with the metal surface to form iodides.
Test 3 was performed at $T = 160^\circ$C under steam-condensing conditions. The same phenomena as in test 2 were observed. The important result of this test is that the $I_2/I^-$ conversion has practically the same value as at $T = 120^\circ$C. Consequently, the activation energy for the $I_2/I^-$ conversion under steam-condensing conditions is zero in this temperature range.

3.4 Discussion and conclusions

The gas phase deposition rate constant for $I_2$ on steel surface in dry air has been measured in the present work at $T = 120^\circ$C with steel material as employed in German plants. The difference of one order of magnitude to the already existing literature value [2] cannot be attributed clearly to one parameter based on the existing test results. Nevertheless, the activation energy determined in [2] should also be applicable to the interaction of $I_2$ with the German steel 1.4541.

The important phenomenon in the $I_2$/steel tests under steam-condensing conditions is the $I_2/I^-$ conversion. This process showed no temperature dependency in the range $120^\circ$C - $160^\circ$C. Condensation rates as expected in severe accidents were used for reasons of transferability.

The $I_2/I^-$ conversion in the aqueous phase and in the gaseous phase under steam-condensing conditions appears to be a similar process. However, the $I_2/I^-$ conversion rate constant in the aqueous phase ($\approx 1E-5$ m/s) is quite different to the gaseous phase (1.4E-3 m/s) at the same temperature ($\approx 140^\circ$C). This points to different reaction mechanisms in the liquid and in the gas phase.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

"The Reaction of Iodine (I$_2$) with Surfaces"
AEA-TRS-2015, November 1990

"Fission Product Deposition and its Enhancement under Reactor Accident Conditions:
Deposition on Containment System Surfaces"
BMI-1865, Columbus, Ohio, USA, May 1969

"IMPAIR/3: A Computer Program to Analyze the Iodine Behaviour in Multi-
Compartmental of a LWR Containment"
PSI-Bericht Nr. 128, September 1992

"Chemical Behavior of Radioiodine in BWR Systems"
J. Inorg. Nucl. Chem. 42 (1979) 1093
### TABLES

<table>
<thead>
<tr>
<th>Test</th>
<th>Temperature (°C)</th>
<th>Gas</th>
<th>Pressure (mbar)</th>
<th>Gas flow (l/s)(^1)</th>
<th>Condensation rate (g/cm(^2)s)</th>
<th>Contact time (s)</th>
<th>Test duration (s)</th>
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<td>air</td>
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</table>

1) standard temperature and pressure

**Table 1:** Boundary conditions in the gas phase I\(_2\)/steel tests (containment conditions).

<table>
<thead>
<tr>
<th>Test</th>
<th>Temperature (°C) / Gas</th>
<th>([I_2])(_a) (mol/l)</th>
<th>([I_2])(_e) (mol/l)</th>
<th>([I_2])(_s)(^1) (mol/dm(^2))</th>
<th>([I_2])(_s)(^2) (mol/dm(^2))</th>
<th>(k_D) (m/s)</th>
<th>(k_K) (m/s)</th>
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<td>2.10E-8</td>
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<td>1.97E-7</td>
<td>6.3E-5</td>
<td>-</td>
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<td>120 / steam</td>
<td>1.59E-8</td>
<td>9.81E-9</td>
<td>1.50E-7</td>
<td>3.74E-6</td>
<td>-</td>
<td>1.4E-3</td>
</tr>
<tr>
<td>3</td>
<td>160 / steam</td>
<td>2.20E-8</td>
<td>1.32E-8</td>
<td>1.47E-7</td>
<td>3.65E-6</td>
<td>-</td>
<td>1.3E-3</td>
</tr>
</tbody>
</table>

1) Iodine concentration on the steel surface at end of test
2) Iodine concentration on the steel surface at end of test plus fraction of iodine that has been washed off into the condensing vessel.

**Table 2:** Experimental results in the gas phase I\(_2\)/steel tests (containment conditions).
Figure 1: Experimental setup for the study of the $I_2/I^-$ conversion at steel surfaces in the aqueous phase at $T = 50^\circ C$ and $T = 90^\circ C$. 

1. Magnetic stirrer
2. Contact thermometer
3. Glass Tube
4. Activated charcoal
5. Sampling line
6. $I_2$ dosing
7. Steel coupon
8. Glass holder
Figure 2: Experimental setup for the tests in the aqueous phase at $T = 140^\circ\text{C}$.
Figure 3: Processes taking place in the reaction vessel for the $I_2$/steel reaction in the aqueous phase. These different reaction paths have to be considered in the data evaluation. The "background" reaction ($k_u$) is presumably caused by the glass surface.
Figure 4: Experimental data points in the main test including steel coupons at $T = 90^\circ$C. The upper diagram shows $I_2$ concentrations in the reaction vessel, the lower part gives the $I^-$ concentrations. The lines are fitted to the data according to the model described in section 2.3.
Figure 5: Experimental data points in the blind test without steel coupons at $T = 90^\circ$C. The upper diagram shows $I_2$ concentrations in the reaction vessel, the lower part gives the $I^-$ concentrations. The lines are fitted to the data according to the model described in section 2.3.
Figure 6: Temperature dependency of the $I_2/I^-$ conversion rate constant in the aqueous phase. The slope of the fit curve yields the corresponding activation energy (8.1E+4 J/mol). The two $T = 140^\circ$C data points are somewhat shifted to each other for reasons of clarity.
Figure 7: Experimental setup for the I₂/steel reaction in the gas phase under containment conditions.