Feedback from Practical Experience with Large sodium Fire Accidents

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ABSTRACT

The paper reviews the important feedback from the practical experience from two large sodium fires; the first at ALMERIA in Spain and the second in the Na laboratories at Bensberg, Germany.

One of the most important sodium fire accidents was the ALMERIA spray fire accident. The origin of this accident was the repair of a valve when about 14 t of sodium was spilled in the plant room over a period of ½ hour. The event has been reported (IAEA/IWGFR meeting in 1988) and this presentation gives a short review of important feedback. The Almeria accident was one of the reasons that from that time spray fires had to be taken into account in the safety analyses of nuclear power plants. Due to the fact that spray fire codes were not available in a sufficiently validated state, safety analyses were provisionally based on the feedback from sodium fire tests and also from the Almeria accident itself. The behaviour of spray fires showed that severe destruction, up to melting of metallic structures may occur, but even with a large spray fire is limited roughly within the spray fire zone itself. This could be subsequently be predicted by codes like NABRAND in Germany and FEUMIX in France.

Almeria accident has accelerated R&D and code development with respect to spray fires. As example for a code validation some figures are given for the NABRAND code.

Another large sodium fire accident happened in 1992 in the test facility at Bensberg in Germany (ILONA). This accident occurred during preheating of a sodium filled vessel which was provisionally installed in the basement of the ILONA test facility at Bensberg. Due to failure of a pressure relief valve the pressure in the vessel increased. As a consequence the plug in a dip tube for draining the vessel failed and about 4,5 t of sodium leaked slowly from the vessel. The plant room was not cladd with steel liners or collecting pans (it was not designed for permanent sodium plant operation). So leaking sodium came directly in contact with the concrete floor and walls. Sodium concrete reactions and concrete destruction were the consequence.

The Almeria accident had previously drawn attention to the potential problem of Na aerosol release into the environment. As consequence the local environment protection group took samples of the air around the Bensberg facility during the accident. No noxious fall out has been found although post accident analyses have shown that the amount of released aerosols was about 1000 kg. The accident confirmed also that severe damage was limited to the immediate fire zone. Neither the Almeria spray fire accident nor the ILONA sodium concrete reactions would have endangered the nuclear safety if they would have occurred at a reactor plant (not speaking of investment losses). The ILONA building was cleaned. After repair the building was ready for another use.

1 SODIUM FIRE ACCIDENT IN THE ALMERIA SOLAR PLANT

This accident happened in august 1986 in the Central Reciever System CRS of the Small Solar Power Systems SSPS nearby Almeria in the south of Spain. It has already been reported in an IAEA/IWGFR meeting [1] and this presentation, after some laps of time, gives now a short review of important feedback.

1.1 Plant description

Objective of the installation :

Various solar energy conversion principles coexists on the test site. The goal of the CRS was to demonstrate the feasibility of electrical power generation by the conversion of direct solar radiation into thermal energy, and then, by conventional methods, into electrical power.

The CRS consisted mainly of a heliostat field which reflects the sun radiation into the receiver, which absorbs and transfers the thermal energy to the sodium fluid. The sodium fluid acts as heat transportation and heat accumulation fluid as well. The energy is used to drive a conventional steam power generation system.

Building, Arrangement :

The sodium part of the plant was mainly housed in a steel framework building erected on an concrete walled basement and cladd with corrugated sheet. The building was ventilated by several roof fans. There was no specific design requirement besides conventional building specifications.

The steam generator and the control and computer plant were in the same building in neighbouring rooms. These rooms were separated from the sodium plant room by fire protection walls in solid -brick lining and usual fire-retarding doors. The machine hall was in an adjacent part of the building. There was no separation wall between the upper part (+ 4,00 m) of the sodium plant room and the machine hall. The resulting opening section between the + 4,00 m level and the roof was several tenths of m^2.

Table 1 : Main Dimensions of the Building (See also figure 1)

surface of ground floor	15,60 x 14,40 m
basement level	- 3,70 m
leakage collecting pan level	- 2,00 m
main steel grating level	± 0 m
upper steel grating level	+ 4,00 m
roof height	15,50 m

Sodium Plant :

The functional principle of the sodium plant was to receive the sun energy, to store it and to deliver it to the steam generator. The energy storage capability amounts to 1 MWh(e). The storage system was based on 2 storage vessels operating at nearly constant temperature levels of about 275 °C for the lower level and about 530 °C for the upper level. One centrifugal circulation pump is associated with each temperature level.

Sodium plant equipment and auxiliaries like argon cover gas system, cold trap, cold trap regeneration vessel, plugging indicator, thermal insulation, trace heating, valves (steel bellows and glands) provided usual sodium plant operating methods and conditions.

The bulk of sodium pipework was arranged in horizontal extension between the ± 0,00 m level and the + 4,00 m steel grating.

Table 2 : Relevant Data of the Sodium Plant :

storage vessel centre line level	± 0 m
storage vessel dimensions	3,3 m Ø x 9,8 m length
total volume per vessel	70 m^3
main pipe diameter	DN 80
auxiliary pipe diameter	DN 50
cover gas operating pressure	1,5 ...8,5 bar absolute
material of Na containing structures	austenitic steel 1.4948
nominal power	2 464 kW
nominal storage capacity	1 MWh(e)

Fire Protection Equipment :

- sodium leakage collecting pans on each bottom floor (total about 300 m^2
- local leak detection systems in collecting pans
- smoke detection system (1 probe for 30 - 60 m^2 of room surface)
- several mobile sodium catch pans
- 470 kg of GRAPHEX powder
- several tenth of mobile fire extinguishers, 6 kg GRAPHEX each

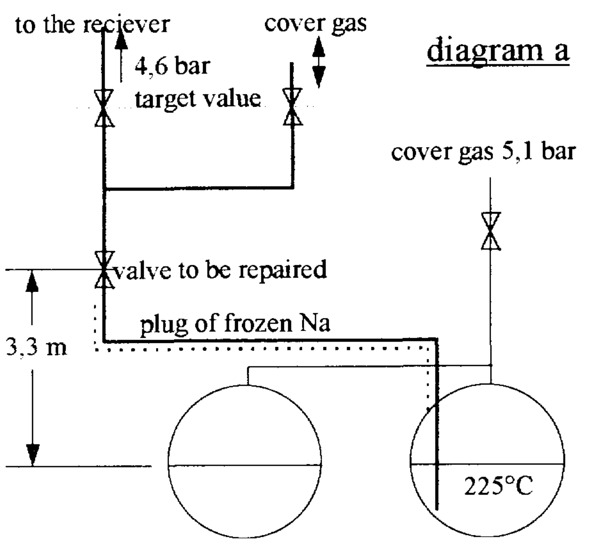
1.2 Origin and accident sequence

Preliminary remark : Due to the fact that the fire propagated from the sodium plant to the control and computer rooms the whole electronic equipment and data recording from the operating period before and during the accident were destroyed.

The plant was on cold shut down for repair of a sodium valve DN80. Several days before, a small leak on the gland of the valve was visually detected (figure 2 shows a cross section of the concerned standard valve DN80).

The valve to be repaired was the first one in the suction line of the "cold" circulation line. The normal cover gas pressure of about 5 bars was to be maintained.

In order to isolate the repair area the following conditions have been created in the system (see diagram a)



- several valves were closed in the upper part of the sodium plant
- sodium was frozen over a length of several meters in the suction line.
- the necessary height of the sodium column was adjusted by creating a pressure difference of 0,6 bar between the upper and the lower part of the system.

- The lantern of the valve should be removed in order to get access to the sealing bellow. After preparing the access and removing the flange bolts operators start hand grinding of the seal weld of the flange (believing that the repair area is depressurized and well isolated from the cover gas pressure and from the cold sodium storage vessel).

- During the first period of grinding the seal weld the leak tightness was maintained by an auxiliary helicoflex seal. When about 2/3 of the seal weld perimeter were cut the helicoflex seal gave way. By this the flange was suddenly lifted up. Several gulps of gas with sodium aerosols were expulsed, followed after a few seconds by a strong sodium jet. This was the begin of a violent sodium spray fire.

- Operators had just time to leave the plant room. Two or three minutes after recognising the accident the operator (three of them were wound by the sodium jet) tried to start the pressure release. But the valves of the argon system did not operate due to lack of energy. So the emergency power supply was started. At the start up of the emergency energy supply, when signals and energy were sent to the actuators, the installation in the plant was already damaged. Whatever the reason, the sodium jet could not be stopped by active measures.

Among the destruction found after the accident was the rupture of a sodium filling nozzle DN80 on the "hot" storage vessel which was located within the spray zone. On its upper end this nozzle was closed by a valve DN 80 which, by its own mass, teared the nozzle down and broke the tube. The cross section of the destroyed tube formed an efficient pressure relief opening. This stopped sodium expulsion without the operators action after about 30 minutes of spray fire.

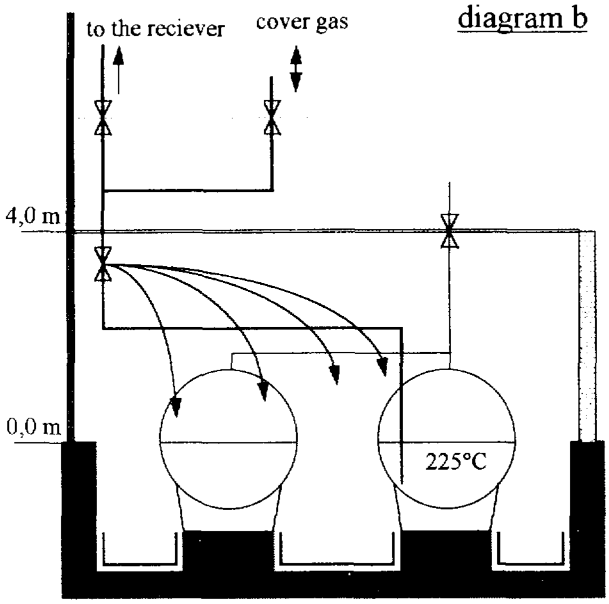
Obviously during that time fire extinguishing was not efficient. After the spray fire stopped a pool fire remained mainly in the sodium collecting pan. This was stopped after 2 hour by GRAPHEX.

Table 3 : Initial conditions and accident sequence data :

sodium temperature	225 °C
sodium volume in each vessel	30 m^3
total gas volume in both vessels	80 m^3
argon pressure	5,1 bar
smallest leakage cross section in the damaged valve	11,25 cm^2
pressure loss coefficient correlated to this cross section	120
driving pressure difference at start of spray	4,1 bar
leak rate	14 kg/s
totally leaked sodium mass	15 m^3
duration of spray fire	½ hour
total duration of the fire	2 hours

1.3 Damage are and material behaviour under sodium fire loads

1.3.1 Spray direction



The valve was located in a horizontal section of the line which was in parallel to the a wall of the building at one meter below the + 4 m level floor. The opening of the flange was limited by the spindle to an angle of 40° and oriented to the middle to the room. Figure 3.

As a consequence the sodium jet was projected horizontally to the middle of the room spraying through the installation zone across the cold storage as shown by diagram b.

1.3.2 Damage area and damage

The spray extenuated horizontally in an elliptic section of about 10 x 5 m and vertically from the bottom to the top of the building. A section of 12 m^2 of the roof material (corrugated sheet) was distroyed. This opening increased the natural ventilation and the oxygen transport to the fire zone.

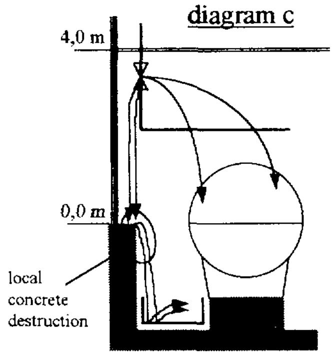
Visual inspection after the accident showed that the area of highest temperature was at a distance of 1 to 3 m from the spray source. Damage happened within the fire and spray zone and concerned the following type of material :

Table 4 :

damaged material	type of damage
ferritic steel	failure of thin support structures (bars $\varnothing \leq 10$ mm), local ductile deformations of support structures and collecting pans
austenitic steel	pipe ruptures as consequence of support failure
galvanised iron	cladding of thermal insulation, gratings, stairs
aluminium alloy	casings of valve driving motors
electrical systems and I&C	in the fire zone and secondary fires

Due to the nature of sodium fires (short flames, strong aerosol production), the propagation of the fire was limited to the ways of the natural convection. Therefore there was no real damage of sodium plant material outside of the fire zone. Only inflammable structure which came in direct contact with the hot convection gas has caught fire (see below : computer room).

Even within this zone no heavy structures like the storage vessels or sodium pumps were significantly attacked by the fire. Steel profiles of the gratings were locally deformed but not destroyed. Only within the inner fire zone smaller supporting profiles suffered ruptures.



The large vessel supports were locally deformed at the edges, but did not fail although the vessels held the normal contents.
Sodium catch pans built of flat ferritic steel plates collected the unburnt sodium, debris and hot reaction products. Although these catch pans were significantly deformed by thermal loads (hot spots) they were able to fulfil their task satisfactorily.

1.3.3 Sodium concrete reactions

Attacks to the concrete were limited to a small place vertically below the concerned valve. Sodium dropped down on the foundation of the basement. Several cm^2, depth max. 10 cm at the upper edge of the wall were attacked.

The reacted concrete volume was only several cm^3 and therefore not able to influence the accident sequence.

1.3.4 Fire propagation to neighbouring zones and rooms

The convection was accelerated by the violent energy release and the wide ventilation cross sections (distroyed roof). So the fire took the following propagation ways :

- vertically upwards ---> destruction of 10 m^2 roof
- horizontally into the computer room (the fire protection door incidentally open)

<u>No propagation occurred :</u>

- downwards to the machine hall
- to all other adjacent rooms (fire protection doors closed)

1.3.5 Temperature determination by material analysis

Material samples were taken in order to determine temperatures and gradients by metallographic analysis and to get feedback from material behaviour. Figure 4 shows a plan of the 4,00 m grating and indicates the location of the samples.

As an example of the failed material a broken austenitic tube is shown by figure 5. The following table 1 gives a summary of the material analysis results.

Table 5 : Excerpt of Material Analysis Results

localisation	material	material temperature	type of damage
center of spray fire, 1...3 m from spray origin in spray	Na-pipework austenitic steel, wall thickness 3 mm	1450 °C at the rupture surface (nearly melting temperature)	total rupture of 1 sodium tube and one sodium nozzle DN 80, due to failure of ferritic support beams 10 mm Ø
direction	Na-pipework austenitic steel, wall thickness 3 mm	1200 °C within the material	
	ferritic steel I-profile, 115 mm, 4,00 m grating		deformation and weakness of the material
surroundings of the spray fire center	galvanised iron gratings	1100 °C	destruction
	support beams	1100 °C	rupture of support beams 10 mm Ø
boundary of the spray fire region	casing of a valve drive motor, aluminium	620 °C, melting temperature of Al	partial melting of casings

1.3.6 Aerosol behaviour

Due to the fast sequence of the accident only a few observations have been made by the operators. Most of the aerosols were transported to the outside of the plant room and even far beyond the site boundaries. No air or earth samples were taken. As usual in that region the weather was dry; so the aerosols leaving the plant should rapidly be transformed to sodium-bicarbonate. No noxious reaction became known from the environment.

Within the plant aerosol deposits were partially transformed in alkali.

The material samples (see chapter before) were taken two months after the accident. At that time no significant alcali attack was observed.

2 SODIUM FIRE ACCIDENT IN THE ILONA TEST FACILITY AT BENSBERG

This accident happened September 1992 in the sodium test facility at Bensberg in Germany. It has been reported in the Fifth DeBeNe - Franco - PNC Specialists' Meeting on Sodium Fires and Radiological Consequences of Postulated LMFBR Accidents in March 1993, Karlsruhe, Germany.

ILONA was a large sodium test facility for natural convection in decay heat removal loops with down scaled components (1/3) and full size elevation. The origin of the accident was not ILONA itself, but a provisional installation in the basement of the ILONA plant.

2.1 Plant description

Building, Arrangement of ILONA:

The tower shaped ILONA building (figure 6) is erected in steel framework construction on a concrete basement. In the basement (figure 7) the following components are installed :

- the ILONA dump vessel
- Provisionally two smaller sodium vessels

In the upper part of the building there are the plant rooms for the sodium test loop which is designed to the usual sodium plant technology standard. The building is cladd with uninsulated corrugated steel plates. The floor of the basement had a normal cement layer of 6,5 cm thickness. The ceiling of the basement is formed by the sodium collecting pan of the floors above. These pans are to collect the sodium in case of a leak in the test loops and to protect the basement against secondary damage.

In normal test loop operation the basement contains only the ILONA dump vessel and nothing else.

Table 6 : Main Dimensions of the Building:

surface of ground floor	11 x 15 = 165 m^2
basement level	- 5,00 m
leakage collecting pan level	± 0,00 m
upper steel grating level	+ 4,00 m
room volume	825 m^3
roof height	+ 36,5 m

Sodium Plant :

The task at the time of the accident was to store provisionally and to accept sodium from another plant on the site. The plant consisted mainly of the two sodium storage vessels. They were connected with an argon supply system and provided with pressure regulation and monitoring system but had no process connection to the ILONA facility. The vessels remained from two older test loops which were formerly dismantled : the 5 MW-Test loop and the AVB (plant operation test loop). Corresponding to its function the installation was simple. The only sodium line DN 25 connected the two vessels. The 5 MW vessel had a dip pipe with gland plug obturation for dumping. See the following diagram d.

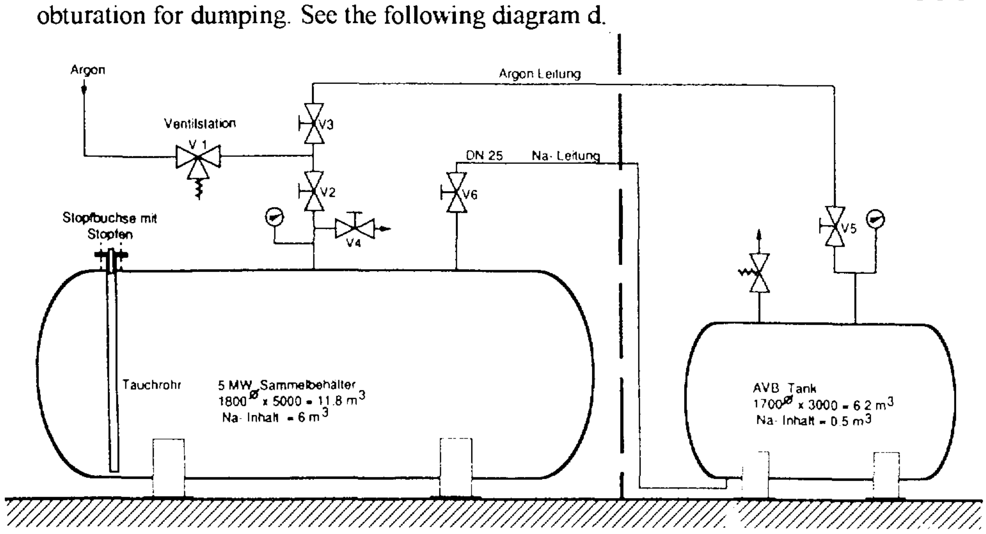


Table 7 : Relevant Data of the Sodium Plant :

	5 MW vessel	AVB vessel
dimensions	1,8 m Ø x 5 m length	1,7 m Ø x 3 m length
total volume	11,8 m^3	6,2 m^3
Na-contents	6 m^3	0,5 m^3
cover gas operating pressure	0,02 bar relative	
material	10 CrMo910	10 CrMo910
insulation/ temperature	140 mm/200 °C	140 mm/200 °C
cladding	no	no
electrical heating	yes	yes
sodium line diameter	DN 25	-
others	dip line with gland plug	

2.2 Origin and accident sequence

Preliminary remark : Due to the fact that the fire destroyed the pressure control and monitoring system and also electrical systems, which were installed in the ILONA basement, no data recording from plant conditions before and during the accident was available. However, by presence of other test facilities on the site data and information base of the ILONA accident is better than that of the ALMERIA accident.

In the original plant state the sodium contents of the vessels were frozen. In order to make the sodium transfer the sodium content of the 5 MW vessel was heated and melted by the electrical trace heaters on the vessel wall.

Table 8 : Initial state :

sodium temperature	< 100 °C
sodium volume in the vessel	6 m^3
total gas volume in the vessel	6 m^3
argon pressure control	1,02 bar

Due to a failure of the pressure regulation valves the cover gas control became unavailable during the heating procedure. The increasing gas pressure lifted the gland in the dip pipe and released sodium. About 6 hours after start of heating procedure the fire alarm from the ILONA basement was given by the central fire alarm system.

Probably the gland plug did not open completely the cross section of the dip pipe. A flow resistance remained. Therefore the leakage flow was small (the time which is necessary to melt the sodium may also play a role). Sodium and reaction products were flowing over the tank outside and came easily in contact with the tank surface because there was no cladding. Additional reaction with insulation material and electrical equipment might have enhanced the energy release.

sodium leakage came in contact with the concrete floor and walls. A sodium concrete reaction started. The concrete of the walls spelled off by the thermal effect. The concrete of the floor was lifted by reaction products and the thermal expansion of reinforcement steel.

The same phenomenon lifted the vessel at one end as well. By inclination of he vessel the entrance to the dip tube of the vessel became uncovered and this stopped the leakage.

Table 9 : Leakage sequence data :

leak rate (estimated value)	0,2 kg/s
duration of sodium leakage	5 hours
totally leaked sodium mass	4,0 t
total duration of fire and sodium concrete reaction	14 hours

Table 10 : Accident sequence and actions :

phase	hour/ duration	phenomena	actions	comments
1	15. Sept 13.30 h	first alarm		
2		local fire and aerosol production	local extinguishing seems to be successful	mobile equipment GRAPHEX
3		restart of leakage and fire, strong heat and aerosol release	Further attempts to extinguish. Holes were cut in the catch pan at 0,00 m level in order to drop GRAPHEX.	
			Argon injection with normal plant cover gas system.	Available gas flow too small to cope with violent natural convection.
			Air sampling in the plant environment by local authorities. Extinguishing stopped due to heat and aerosol release.	Negative result.
4	18.00 h	back ground noise from concrete bursting, aerosol production decreased		Obviously stop of sodium leakage.
5	19.00 h	further reduction of aerosol release,	Start of argon flooding from gas transport trucks. First inspections of the room with respiratory equipment and heavy protective suit.	
6	16.Sept 3.45	stop of burning phenomena, start of cooling down phase	Argon cover gas inerting with slowly decreasing argon flow. Temperature, O_2- and H_2-monitoring	debris temperature 450 °C; O_2 < 2 % H_2 < 0,7 %
7	24.Sept until 25.Oct.	transformation of aerosol deposits in carbonate	start of CO_2-admission	debris temperature 100 °C; CO_2 < 3 %

2.3 Consequences

2.3.1 Main characteristics of the fire

The leakage flow rate was small and there was not a "fountain". As found by post accident investigations the leakage sodium flowed along the vessel surface downwards and dropped on the concrete floor. There was no protection by a steel cladding or sodium catch pan.

Consequently the behaviour was that of a pool fire with sodium concrete reaction at the floor.

Table 11 : Mass balance of leakage sodium :

total leakage sodium	4300 kg
sodium implied in reaction with concrete	1000 kg
unreacted sodium found in the debris	300 kg
burnt sodium	3000 kg
sodium transformed in aerosols	2500 kg
sodium transformed in other reaction products	500 kg

2.3.2 Damage area and damage

Table 12 :

damaged material	type of damage
damaged material	construction elements
ferritic steel	local ductile deformation of vessel support and the collecting pan above the vessel
ferritic material with galvanised surface treatment	partial destruction of gratings and stairs
aluminium	destruction of pressure control valves in the fire zone
concrete	see following chapter 1.3.3
electrical systems and I&C	in the fire zone and secondary fires

There was no propagation of fire outside of the concerned plant room. Even within the plant room no distruction occurred a short distance from the fire section and there was no horizontal propagation.

The sodium catch pan on the ceiling of the room was built of flat ferritic steel plates. This catch pan was locally deformed by thermal loads (hot spots at the edge due to convection of hot reaction gas).

2.3.3 Sodium - concrete interactions

The most important observation of the site after the accident was the concrete distruction :

- sodium concrete reaction : mainly the floor of the room and the lower part of the wall
- thermal impact without chemical reaction : walls of the room in those areas which came in contact with the convection flow of hot reaction gas.

2.3.3.1 Sodium concrete reaction

The concerned area was situated under the vessel, more precisely below the part of the vessel were the dip pipe delivered the leakage flow. The concerned floor surface was about 20 m^2.

There the sodium attacked the concrete to a depth of 390 mm. The reaction products increase the concrete volume. This was one of the effect which lifted the vessel and stopped finally the leak. The other was thermal dilatation of reinforcement steel. Exhaustive post accident analyses were made of the concrete damage. Figure 8 shows a cross section and horizontal extent of the sodium - concrete reaction zone.

As maximum concrete temperatures 900 °C were found. In total 2 m^3 of concrete reacted with sodium. The reaction produced hydrogen. The hydrogen combustion increased the surface temperature of the vessel. This was confirmed by lacquer replica technique.

2.3.3.1 Thermal effects

Chemical analyses of the wall concrete showed that only physically bound water was released. Nevertheless, this effect - together with thermal expansion effects - has destroyed 50 m2 of concrete wall. Without, however, calling in question the overall stability of the building. The reinforcement steel was much less deformed than that of the floor concrete. Figure 9 shows a damaged wall section.

2.3.4 Fire propagation to neighbouring zones and rooms

As stated in the previous chapters the fire impact was limited to the floor surface of 20 m^2 and a wall surface of 50 m^2.

<u>No propagation occurred :</u>

- to the higher floors of the plant
  (insofar the sodium catch pan on the 0,00 m level was efficient in both directions : originally designed to protect the basement against leaks in the ILONA tower it was sufficient in the other direction as well).
- horizontally to other installations at the same room (example : the ILONA dump vessel).

2.3.5 Temperature determination by material analysis

Material samples were taken in order to determine temperatures and gradients and to get feedback from material behaviour.

Table 13 : Extract of Material Analysis Results

material	material temperature	type of damage
vessel 10CrMo910	locally about 1000 °C	no visual damage but local modification of microstructure (nearby the main fire zone)
reinforcement steel in floor concrete reaction zone BST500S	> 1000 °C	decrease of material properties
sodium collection pan at 0,00 m ferritic steel	< 800...900 °C	no damage, no modification of microstructure
galvanised iron gratings	1100 °C	destruction
ILONA dump vessel austenitic steel 1.4948	< 900...1000 °C	no damage, no modification of microstructure

2.3.6 Aerosol behaviour

In opposition to local damage of concrete aerosol deposits were found in the whole building.

Table 14 : Aerosol production balance :

burnt sodium	3000 kg
sodium transformed in aerosols	2500 kg
deposits in the building	1500 kg
release to environment	1000 kg

During the period of highest reaction rate the local authorities took air samples in the plant environment. No noxious reaction were found.

Deposits in the plant :
The deposit layer thickness decrease with the floor level of the examined plant room.

4,20 m level	1,16 gram/m^2
29,40 m level	0,44 gram/m^2

Figure 10 shows photographs of aerosol deposits in plant rooms, which had obviously not suffered during the accident.

Several months after the accident the ILONA building was cleaned. The cleaning was accompanied by continuous chemical and material survey. After repair of the concrete damage the building was ready for another use.

3 CODE DEVELOPMENT

Particularly the Almeria accident has accelerated R&D and code development with respect to spray fire and combined spray - pool - fires. In Germany SIEMENS (former INTERATOM) developed the code NABRAND in order to discribe pool and spray fires simultaneously.

3.1 Modelization of energy release

From leakage accidents and a large variety of sodium fire experiments it was learnt that the most effective thermodynamical consequences are produced by sodium jets dispersed after impact (like e.g. the spray fire at Almeria). The code simulates the following input parameters :

- leak rate

- fraction of the leak rate which participates in the spray fire
- extension of the spray zone
- pool burning area.

The sodium droplet size is an important parameter for the burning surface of a spray. The SPRAY subroutine needs as input the droplet size. As a typical size spectrum a log-normal distribution with 4 mm mean diameter and a standard deviation of 2,15 has been identified to be valid for the single droplet burning model. The experiments showed that this is a good assumption for all types of dispersed fires from experiments.

3.3 Modelization of heat exchange

An important feature of the code is the natural convective and the radiative heat exchange between the combustion zone and the aerosol loaden outer gas zone surrounding it. Because of the high heat absorption by the produced aerosols, the heat transfer to the walls and structures of the compartment is done via the outer gas zone. With respect to pressure relief and ventilation different options are possible. Also 1D convective exchange between the compartments connected to the burning cell can be modelised.

3.3 Validation

In order to validate NABRAND code, pre- and postcalculations were compared to experiments that were done recently in order to analyse combined fires at large leak rates in large containments. By these experiments the validation of NABRAND code already done for a large variety of different experiments mainly done from FZK Karlsruhe and CEA Cadarache could be completed.

Table 15 : Sodium Spray Fire Experiments - Comparison with NABRAND Simulations

Experiment	Characteristics		Peak pressure (bar)		At spray time	
	test cell data	spray data	test	code	test	code
IGNA 402	400 m3 pressure relief valves	10 kg/s in 60 s	about 0,03	< 0,04	about 20 s oscillating	
IGNA 2002	2 x 27 m3 pressure relief by 20,6 m2	135 kg/s in 8 s	cell 1 : 0,13 cell 2 : 0,10	model 1 : cell 1 : 0,26 cell 2 : 0,17 Model 2 : 0,21	< 1 s	0,3 s
IGNA 3602 IGNA 3604	3600 m3 4 m2 burst disc	80 kg in 8 s 160/480	max. pressure rise 0,17 bar/s 0,22/0,27 bar/s		4,3 s	4,3 s 3,3/2,6 s
FCA++2 post test :	220 m3 closed 220 m3 closed	15,5 kg/s in 25 s 15,5 kg/s in 25 s	3,2	2,9…3,2 3,3	12…19 s	9…15 s 13 s
FCA 150 post test :	220 m3 closed	150 kg/s in 10 s	32,8	2,2…3,5 2,9	6 s	7 s 5 s

4 CONCLUSIONS

The two reported accidents found wide response in plant R&D, plant design and licensing. They covered two different characteristics of a sodium release, the spray fire and sodium concrete reaction. When the ALMERIA accident happened, spray fire codes had not yet been used in the plant design and licensing. Obviously ALMERIA has accelerateted R&D in this field.

Nearly all relevant phenomena (except reactivity and pressure built up in plant rooms) were present in these events. The German plant SNR 300 became the first where immediate consequences were drawn in R&D and licensing (and sodium fires were one of the political pretexts for the authorities to impede licensing). NABRAND was one of the first codes which was applied in plant licensing as consequence of the ALMERIA accident.

Dispite the spectacular consequences the lessons to be learnt from these fires are not only negative. The accidents happened in test facilities and not in nuclear plants designed in more onerous standard. So the conclusions concerning potential damage are conservative for nuclear plants :

- no toxic release even if large quantities of aerosols are released (besides radioactivity, tritium...)
- propagation only by convection (and not by self sustaining reactions)
- no horizontal propagation beyond the immediate sodium fire zone
- due to this fact protection measures against propagation are simple : normal fire resistant equipment is sufficient
- all steel and concrete which is not in directly contact with the fire do not suffer functional relevant damage
- several material groups such as aluminium and galvanised iron should be avoided for safety relevant equipment
- plant rooms can easily be cleaned and subsequently used

The chief witness for these statements is the ILONA dump vessel : In fact one of the ALMERIA vessels was cleaned and requalified and raised from death as dump vessel for the ILONA test facility. As this presentation illustrates it survived a second large sodium fire without damage.

FIGURES

REFERENCES :

[1] Effects of Sodium Fires on Structures and Materials. Practical Experience with Sodium Leakage Accidents. - K.F. Freudenstein, IAEA/IWGFR Obninsk, 1988

[2] The ILONA Sodium Fire Accident with Sodium Concrete Reaction (Preliminary Analysis). - K.F. Freudenstein, Proceedings of the Fifth DeBeNe - Franco - PNC Specialists' Meeting on Sodium Fires and Radiological Consequences of Postulated LMFBR Accidents. March 1993. Karlsruhe. Germany. (Not published proceedings)

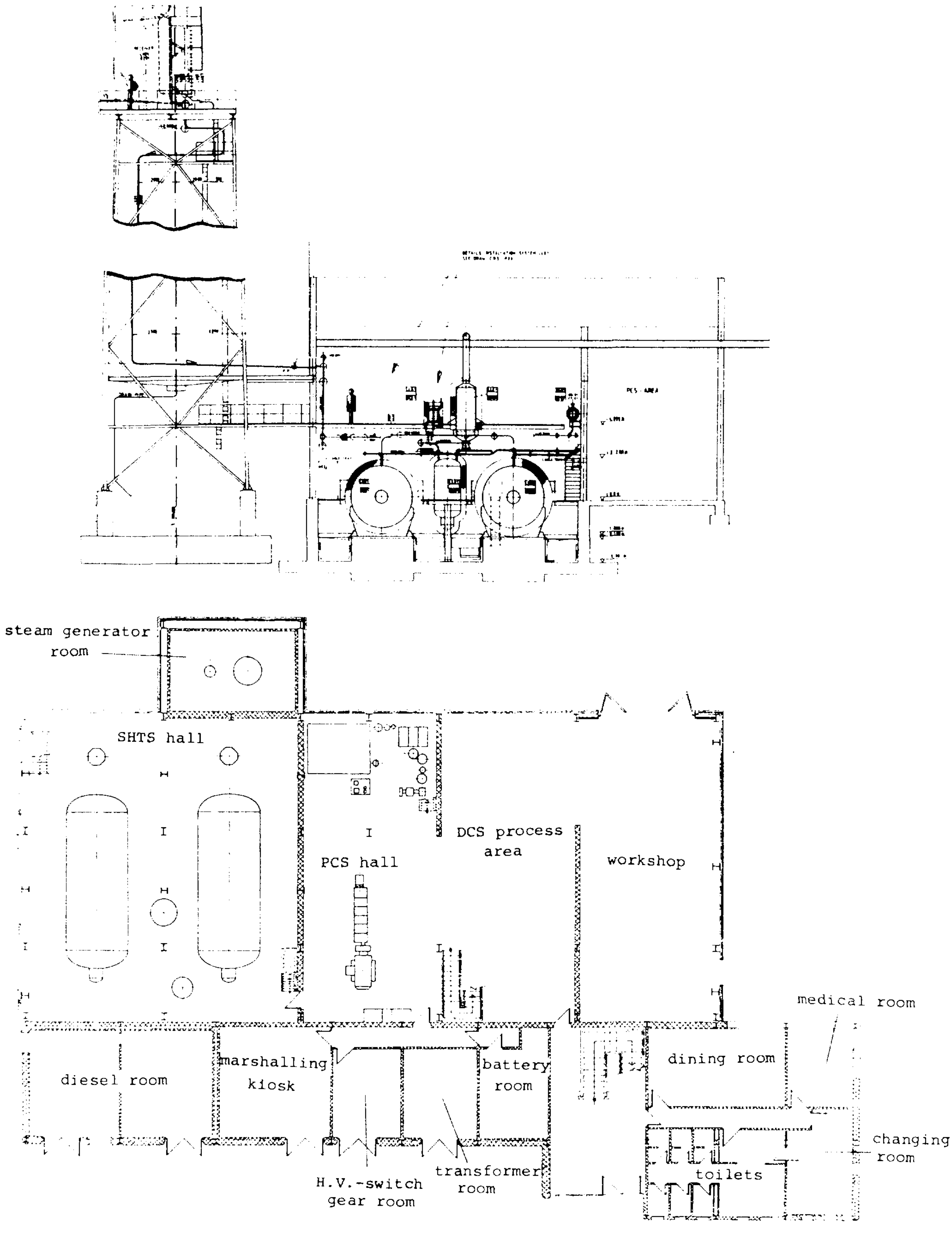


Figure 1 ALMERIA : IEA - SSPS PROJECT CRS - Building Plans

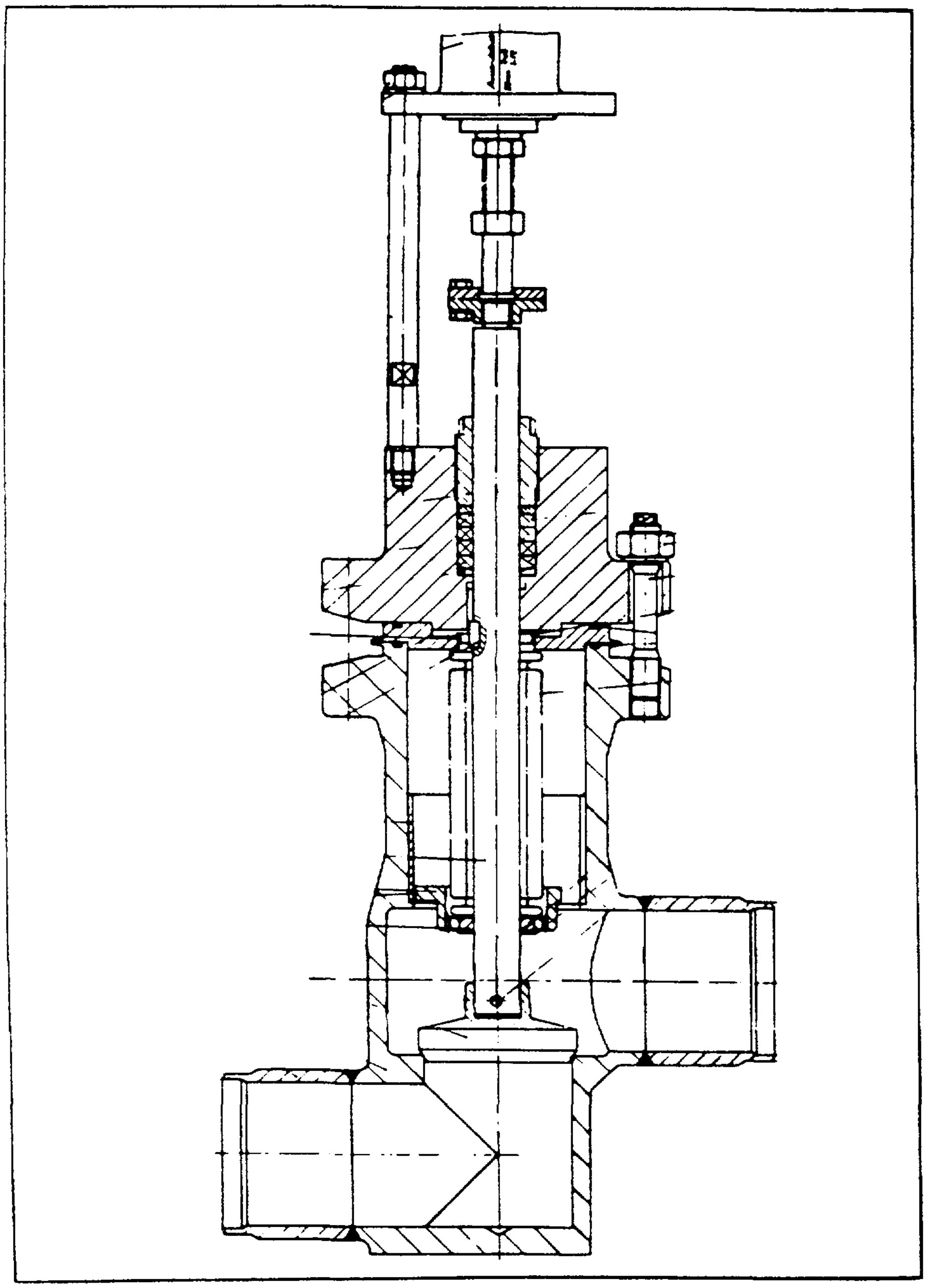
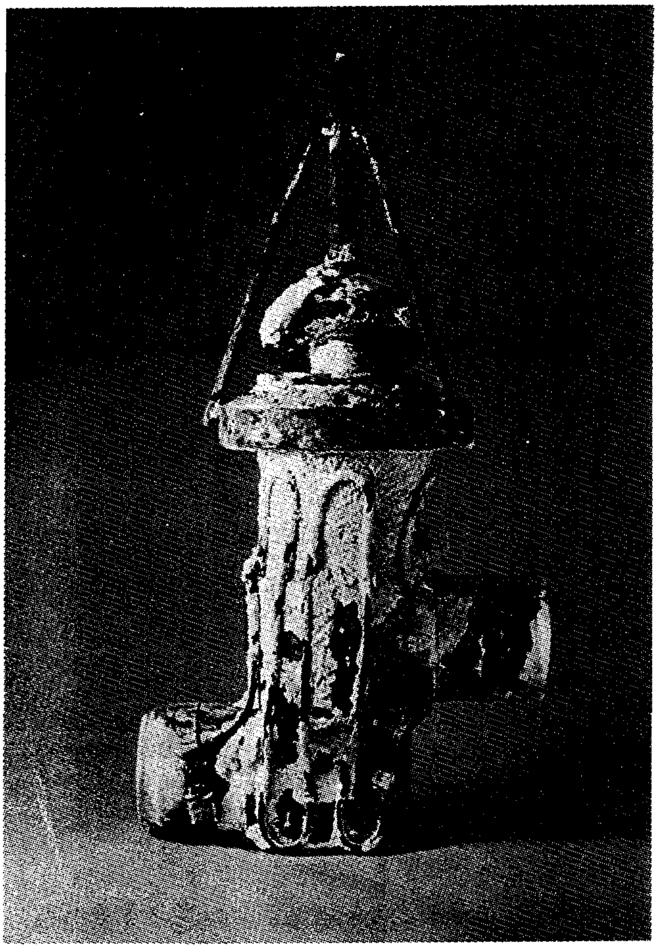


Figure 2 ALMERIA :: Cross Section of the Damaged Valve LK01 AA06



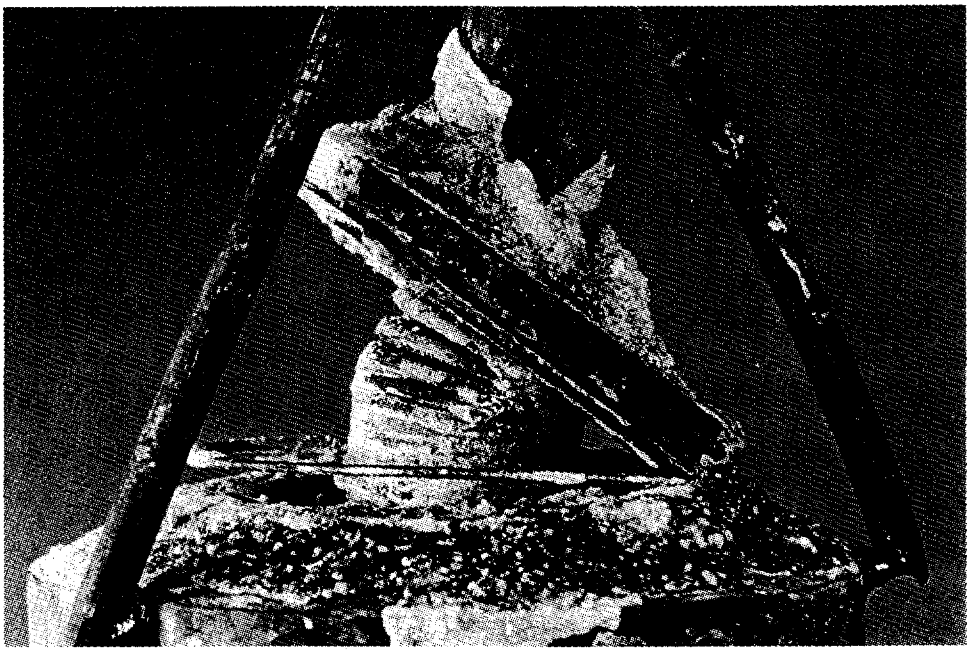


Figure 3 ALMERIA : Photographs of the Damaged Valve LK01 AA06

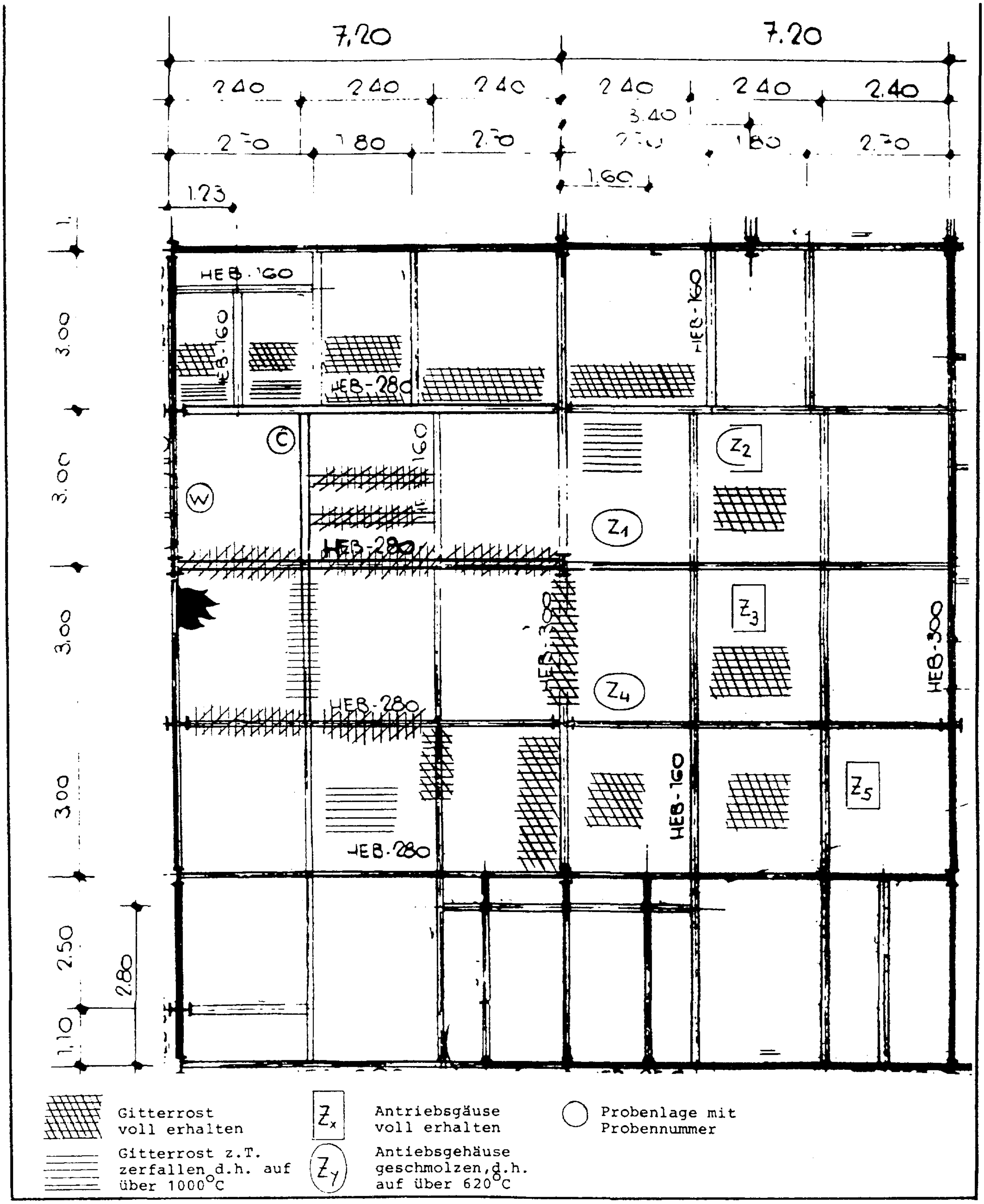


Figure 4 ALMERIA : The 4,00 m grating with positions of material samples

INTERATOM	Abbildungen 2	Notiz-Nr.: 55.08597.1
		Datum: 12.11.86

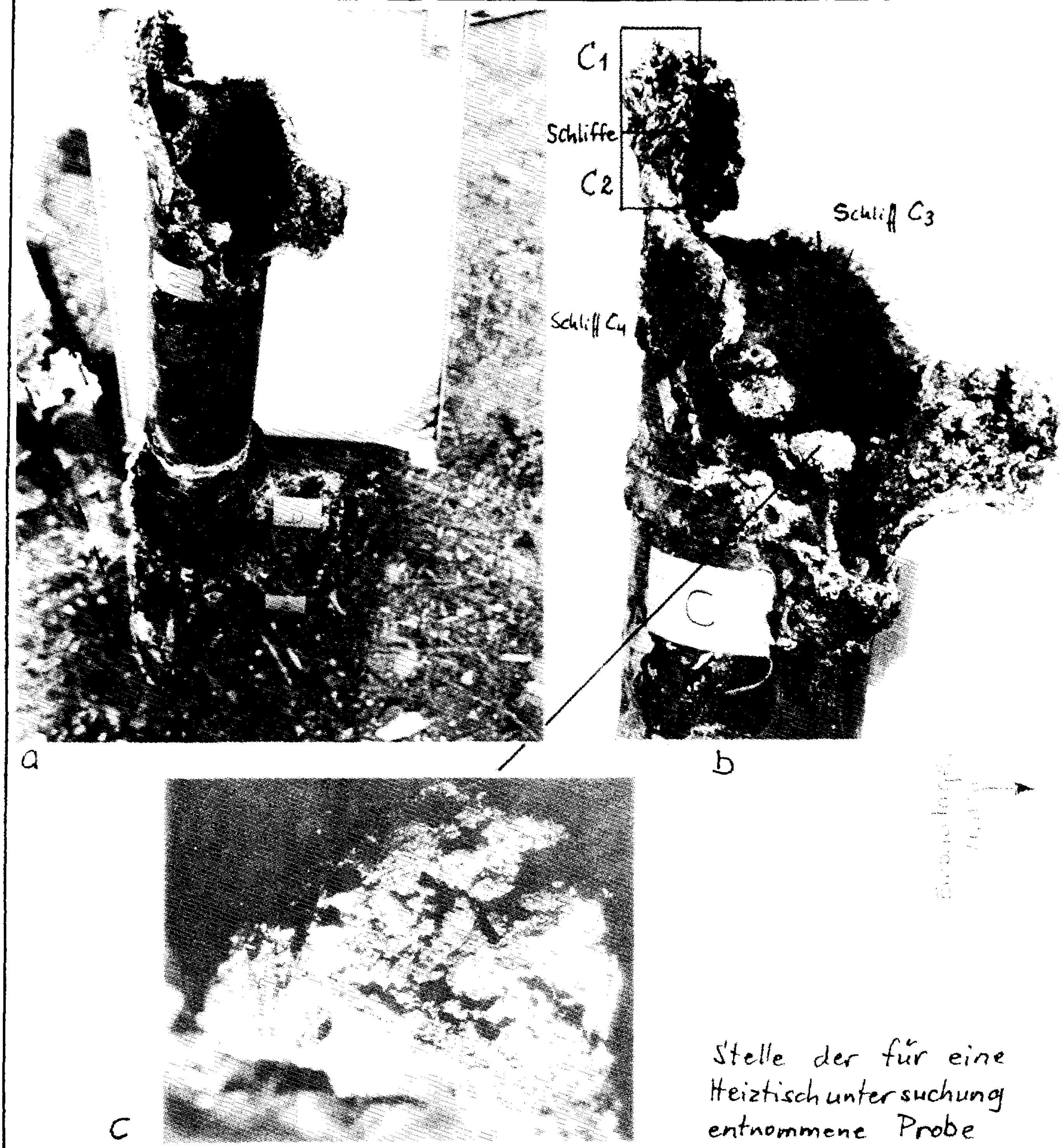


Bild-Nr.	Vergrößerung	Vermerk	Archiv-Nr.
a, b	< 1 : 1	Abgerissenes Rohr und Rohrschelle	
		(Gegenstück zu Pr. K)	
c,	≈ 10 : 1	Oxidkruste mit Metallrest für den	
		Wiederaufschmelzversuch	

Figure 5 ALMERIA : Photograph of a Broken Stainless Steel Tube

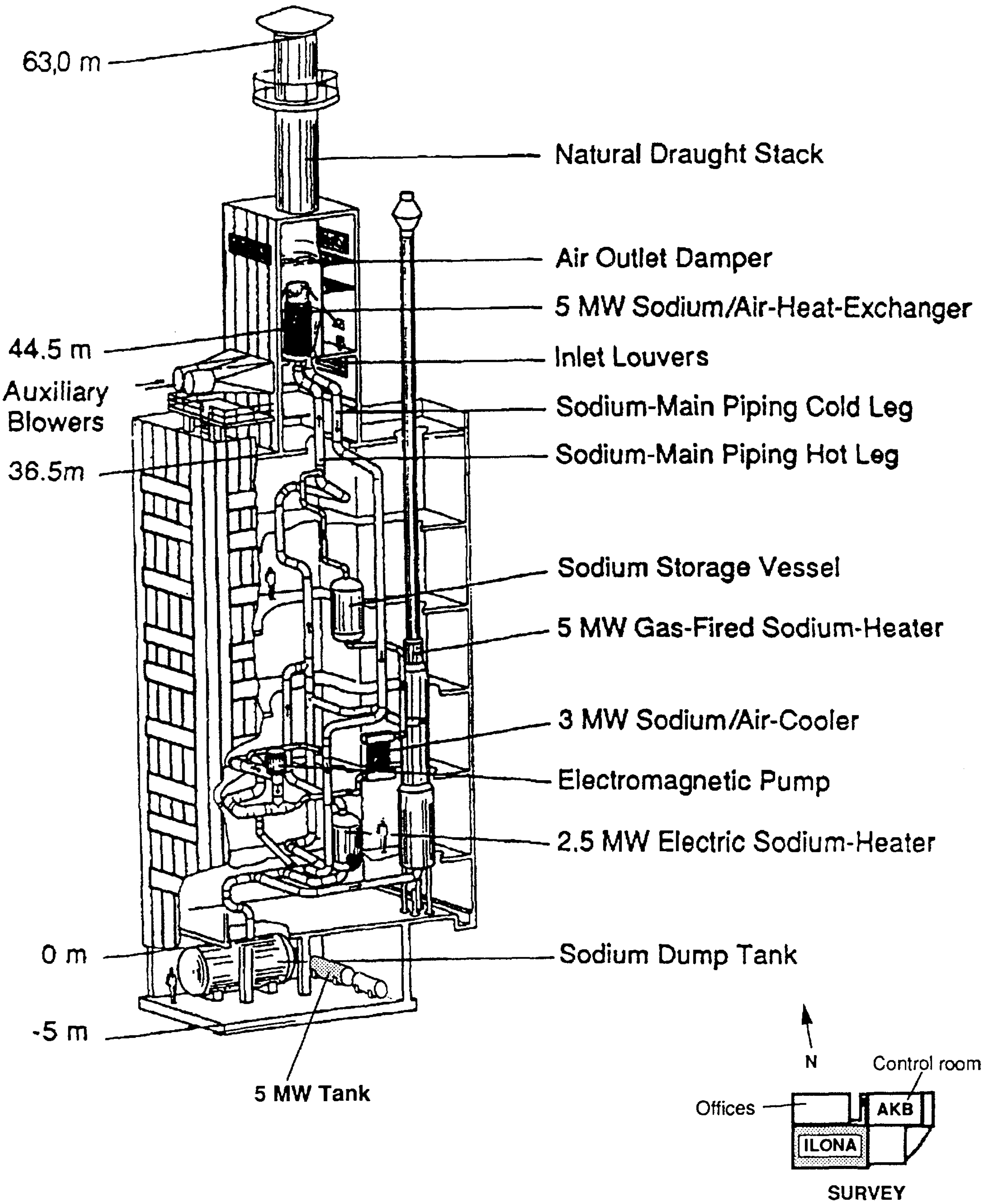
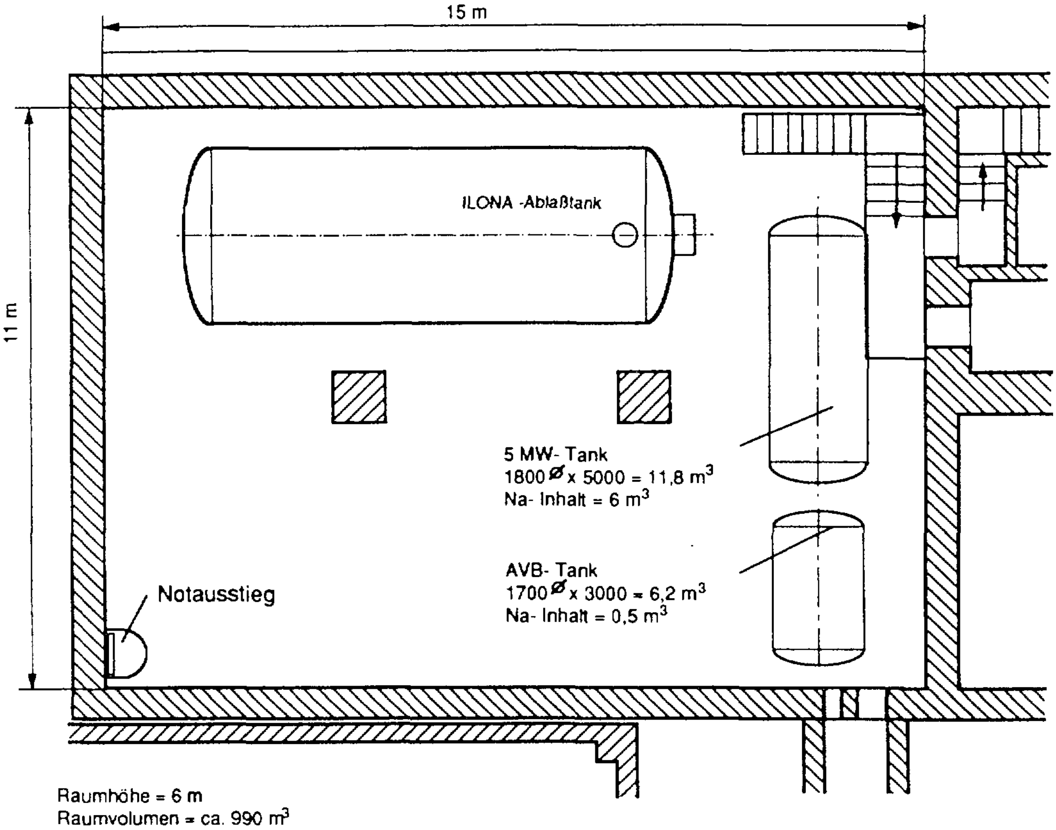
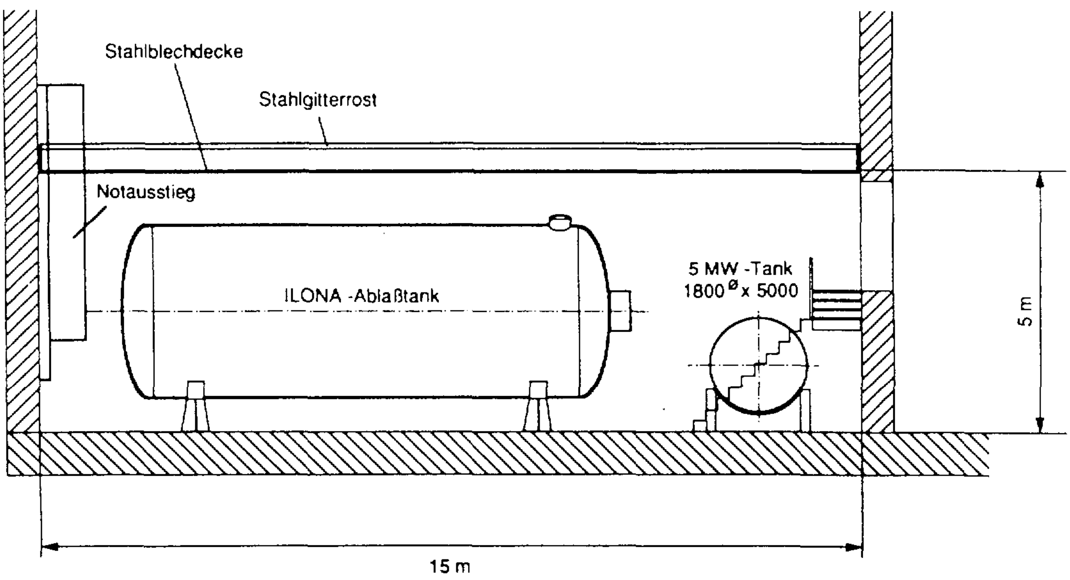


Figure 6 ILONA DHR Test Facility

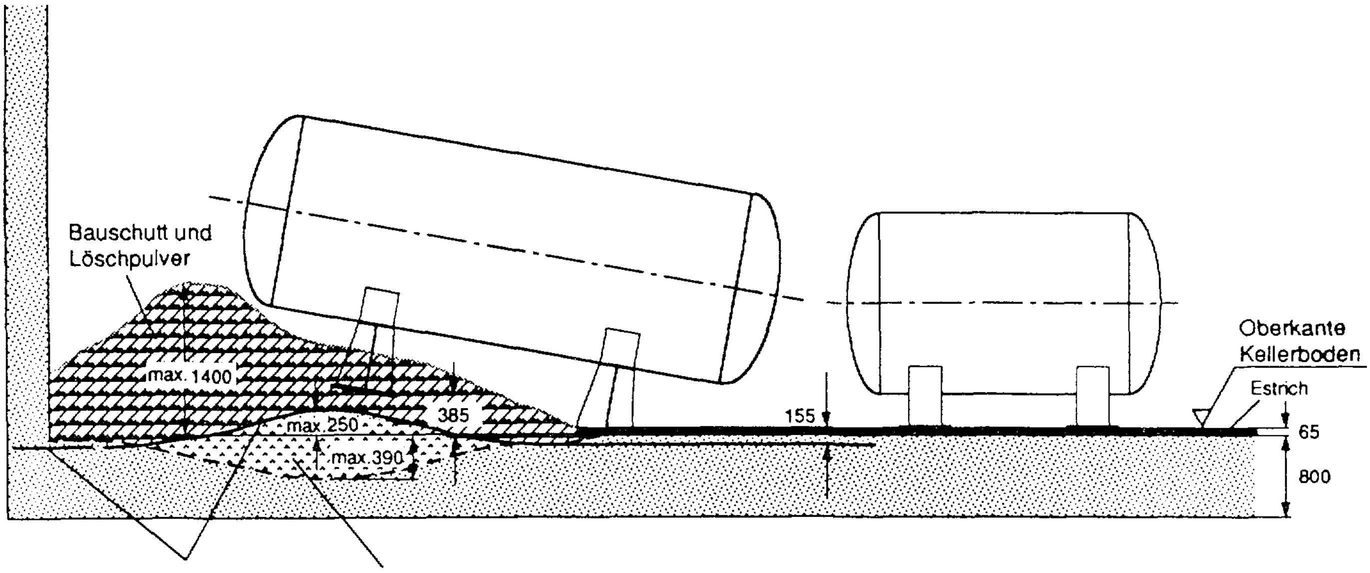


ILONA- Keller Draufsicht

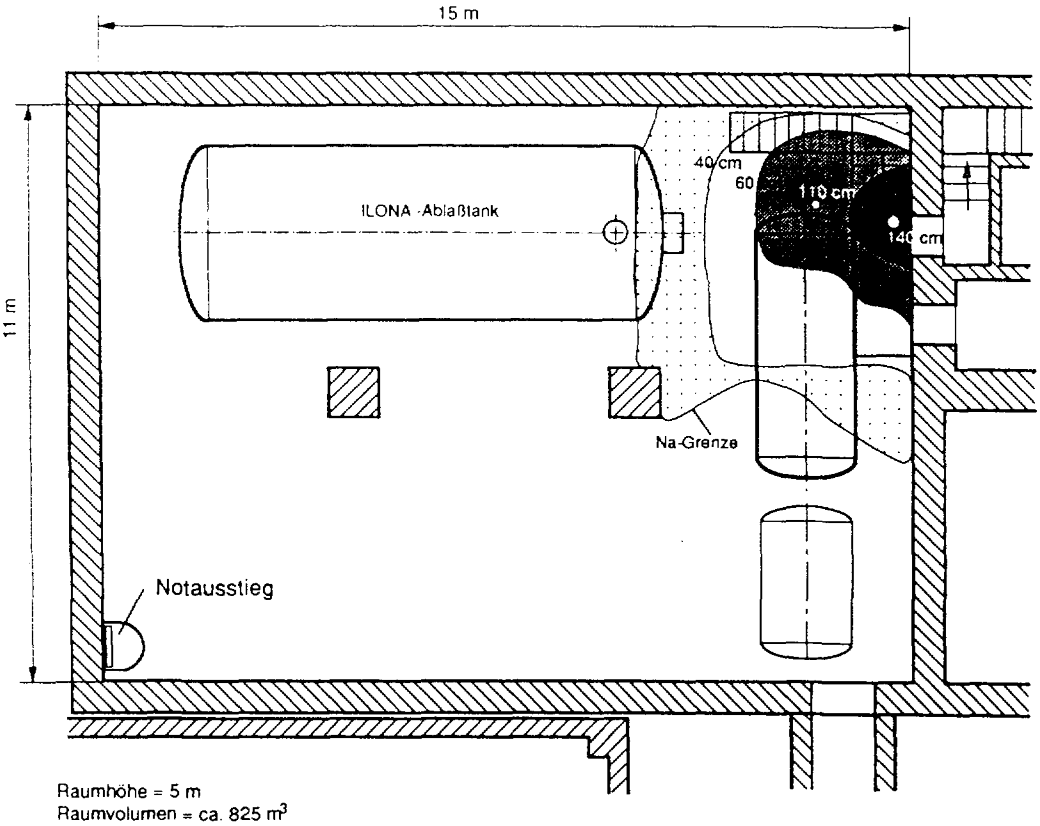


ILONA- Keller Seitenansicht

Figure 7 ILONA : Basement - Plan and Cross Section



Schieflage des 5MW-Sammelbehälters nach dem Brand



Brandzone mit Schuttauflage

Figure 8 ILONA : Cross Section of the Sodium - Concrete Reaction Zone

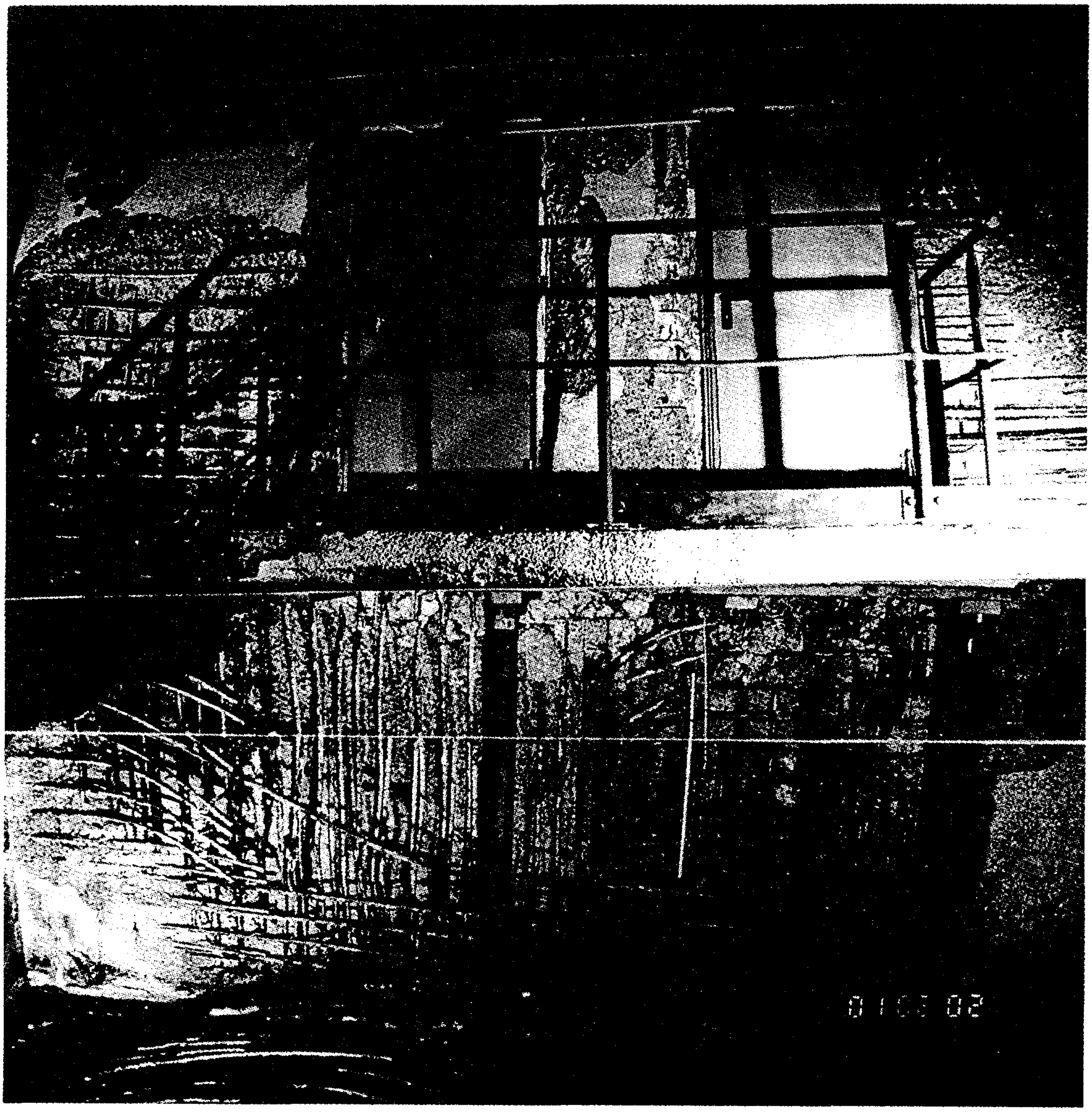
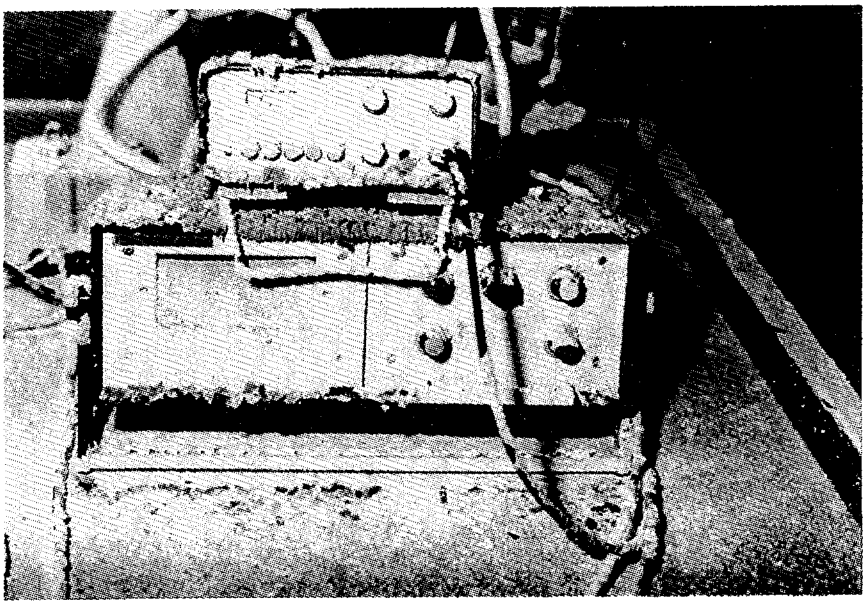


Figure 9 ILONA : View on a damaged Wall Section

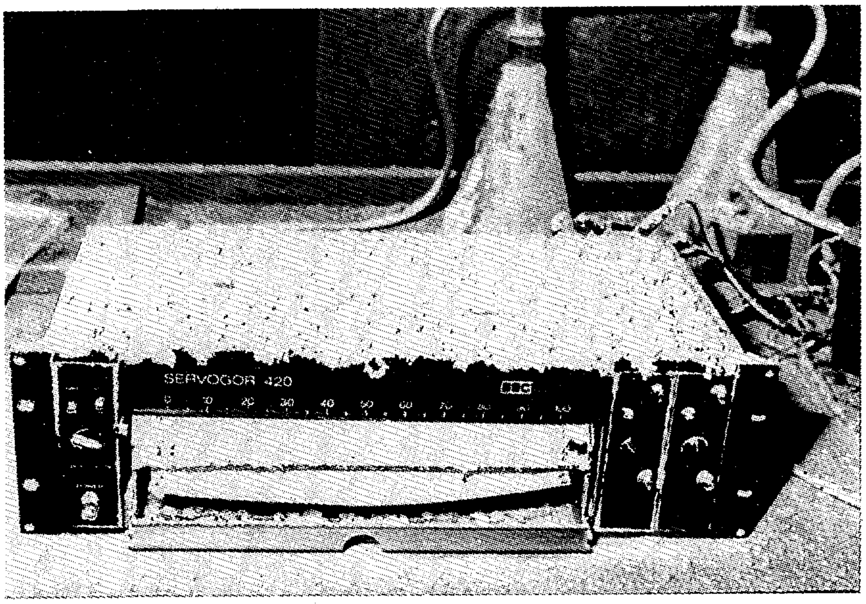
SIEMENS

Figure 10 ILONA : Photographs of Aerosol Deposits in Plant Rooms

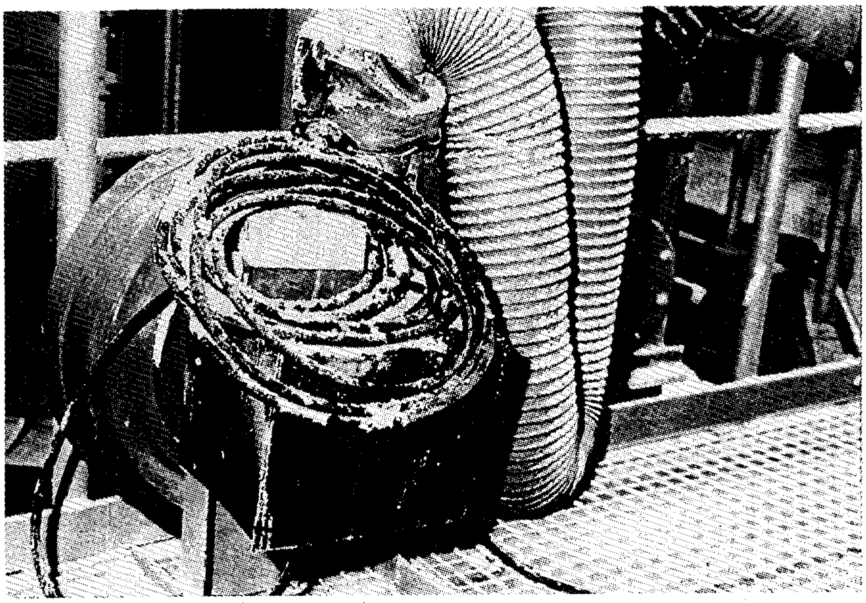
Bühne 3



Bühne 3



Bühne 2



Aerosolbelegung in der Anlage Bildseite: 4