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TECHNICAL REPORT

No. 5/83

Investigations and Findings
concerning the
Sodium Tank Leakages

edited by
W. Bucher
DFVLR, Cologne

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SSPS Technical Report No. 5/83

Investigations and Findings concerning the Sodium Tank Leakages

edited
by
W. Bucher
DFVLR

IEA Operating Agent, DFVLR
Cologne, Germany, July 1983

Introduction

The defects and difficulties experienced with the sodium storage tanks and the power conversion system (Spilling engine) of the SSPS Central Receiver System induced the decision of the 20th Executive Committee to set up a group of experts from international institutions.

This Experts' Group was established to support the Operating Agent to overcome the problems; it reported directly to the 21st EC.

The present document contains:

- The Report by the Experts' Group (Dec. 1982)
- The Concept for Final Solutions of CRS Problems proposed by Interatom (Dec. 1982)
- The Reports on the Cause of Damages by TÜV (Technischer Überwachungsverein) (3 volumes)
- The final statement of the chairman of the Experts' Group after completion of repair.

Some minor modifications of the concepts have been made during the repair works (e.g., in the first phase of planning it was not clear whether to heat-treat or not the cold storage tank).

The papers presented here reflect the point of view at the times of their origin. Only minor corrections have been made. This should be taken into account when the statements of December 1982 and the final remarks of the TÜV Report are compared.

Nevertheless, this publication shows the progress of work and the effort of all parties to ensure satisfactory solutions and operability of the plant.

W. Bucher
Editor

Almeria Solar Power Plant, CRS

REPORT BY EXPERT GROUP

December 1982

1. EXPERT GROUP

Mr. J. Moore, Consultant to EIR, Switzerland, Chairman
Dr. N. Hoffman, Energy Technology Engineering Center (ETEC), USA
Mr. A. Schwarzenbach, Brown, Boveri & Cie, Switzerland
Dr. H. Kohl, EIR, Switzerland

2. TERMS OF REFERENCE

The SSPS CRS Experts Group is composed of members nominated by Mr. Braun and Dr. Kesselring on behalf of the SSPS Executive Committee pursuant to a decision taken at the 20th EC meeting on 23 October 1982 in Claremont, CA.

The group shall be chaired by Mr. J. Moore who will also act as speaker of the group.

The group's mandate is to put a professional judgement on the solutions to be proposed by the company Interatom for curing the deficiencies in the SSPS CRS sodium heat transfer and power conversion systems.

The group's findings shall be drawn up in an English written report for the 21st Executive Committee meeting to be held on 6 and 7 December 1982 in Cologne. The report shall be orally presented by the speaker of the group at the a.m. EC meeting.

The group is free to carry out whatever investigations it deems necessary. It shall consult with the operating agent, the company Interatom, and the Technischer Überwachungsverein Rheinland (TÜV).

The group shall be assisted by the operating agent acting as its secretariat. The operating agent shall advise the chairman of the group on practical matters relating to the group's work. The experts shall be remunerated by the SSPS project.

3. EXPERT GROUP SCHEDULE

Mr. J. Moore	familiarization and personal enquiries
Mr. A. Schwarzenbach	started 18 November
Dr. N. Hoffman	familiarization started 18 November
Dr. H. Kohl	first involvement 26 November

1 December 1982,	meeting in DFVLR offices Cologne
2 December 1982,	presentation by Interatom, comments by TÜV
3 December 1982,	meeting in DFVLR offices Cologne of full expert committee, finalization of report
6 December 1982,	presentation of report to 21st Executive Committee meeting

4. SCHEDULE OF EVENTS

The attached schedule has been prepared to show in a simple way the time sequence of plant faults, "defect events", and the state of operation of major parts of the plant.

There was insufficient time to prepare this schedule with a high degree of accuracy and it would have been desirable to include more detail. In particular, there was insufficient time to identify much relevant data in the early stages, before the plant was taken over by the plant operators Sevillana.

It is recommended that a similar schedule should be maintained by the project, to help keep off-site management informed of significant events occuring on the plant.

5. PLANT DIFFICULTIES

Determination of the reasons for development of cracks on the sodium-filled parts of the plant and of resulting leakages of sodium depends to a large extent on examination of specimens cut from the plant and visual examination. Information of this type has been presented in a number of reports together with opinions as to the cause of failure by those concerned with the examinations.

The following text and that in Section 6 summarize the position as seen by the experts group and present their opinions.

Similarly, Annex 1 reviews available data and opinions relevant to experience with the Spilling CRS. Text in this section and Section 6 give an overview and opinions by the expert-group.

In addition, documentation of the events is being prepared. TÜV is compiling a paper dealing with the sodium leakages, the connected tests and investigations, and the repair procedures. - Interatom and Spilling will submit a detailed description of the events and the measures taken at the Spilling engine.

5.1 Cold Sodium Tank Bottom

Figure 1 shows the cold sodium tank. The three "studs"* shown on the underside were fitted early in 1982 as part of the procedure to deal with sodium leaks and cracking in the bottom of the vessel.

The three vertical pipes above the "studs" are to enable flow of sodium into the tank. Underneath each of these pipes, there is a square "shock plate" welded to parallel rails and subsequently welded to the bottom of the tank. The purpose of the rail-mounted shock plate is to prevent direct impact of hot sodium onto the base of the tank and to reduce thermal shocks to the tank.

All the leakage and cracking events in the tank bottom are associated with these "shock plates" and subsequent repairs. Each of the three plates is attached to the tank bottom by two parallel metal rails that are first welded to the underside of the "shock plate" and then to the tank bottom. Figure 2.

The welds in the tank bottom cannot be made satisfactorily, it is not practical to weld the full length of the inside of the metal rails to the tank bottom. All concerned recognize that this particular feature, the "rail-mounted shock plate", has caused cracks, some leading to sodium leaks, due to one or more of the following:

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* The term "stud" refers to a ring-plus-bowl assembly that is fabricated in situ on the vessel

- O difficulty to weld properly
- O geometric stress concentration factors combining with high residual stresses due to the design of the method of attachment to the tank bottom
- O thermal cycling increasing these stresses.

Interatom has estimated the contribution to failure of thermal cycling caused by the overall changes in vessel temperature and by hot sodium injection, an average four times per day during plant operation. These estimates are included in their proposal document.

The sequence of defect events has been as follows:

Event TB1, July 1981

A weld at the rail bottom of the shock plate associated with the sodium pump return line cracked. Sodium leakage was observed as the crack propagated through the bottom of the cold storage tank.

The ends of the crack were terminated by drilling holes and two plug samples were taken for analysis from these two holes. Ultrasonic examination showed no more cracks. Metallographic examination of one of the plugs indicated circular pores present in the weld bead.

Since the tank bottom now contained a through-crack and two holes, a 165 mm "stud" was welded to the underside of the cold tank. This bowl would fill with sodium as the cold storage tank was filled.

Event TB2, January 1982

No sodium leak. Extensive ultrasonic examination followed by taking plug samples showed various indications of crack starters and partial wall penetration tears. These crack indications were noted after cool-down of the cold storage tank from operating temperature.

The 165 mm stud fitted for event TB1 was cut off. Nine plug samples were taken including those that were cut to terminate identified cracks. Slits were cut in the bottom of the cold tank to relieve stressing of the shock plates and larger studs were fitted under each of the shock plate zones to cover all of the defected and suspected areas of the bottom of the cold tank.

Event TB3, September 1982

Leakage of sodium through a crack in the weld of one of the three studs fitted after TB2. A second crack was also detected. The stud that leaked was associated with the shock plate assembly under the sodium receiver return line.

A repair was made by covering each of the two cracks with an angle piece welded over the crack zone.

Event TB4, October 1982

Leakage of sodium in one of the repair pieces, fitted after event TB3.

Occurrence of this leak led to the decision to close down and re-examine how to proceed.

5.2 Cold Sodium Tank Manhole

The manhole "stud" at the end of the tank, Figure 1, is provided to allow access during installation on site. Part of the stud is fitted to the vessel during manufacture and a circumferential weld joining the two circular sections is the final weld on site that is made when the rest of the manhole stud is connected. Three leaks from cracks in this weld occured in September 1981.

Although the manhole leaks occured approximately five weeks of calender time after the first sodium leak, the actual operating time between leak events was less than 14 days following several days of heating up the cold storage tank to operating temperature. These manhole leaks were ground out and welded over to give a temporary fix until a new manhole "stud" could be installed. In mid-December the cold storage tank was cooled down from operating temperature and in January a new manhole stud was installed.

There were problems during the initial welding operations prior to any operation with sodium.

- O During the welding and acceptance procedure, the weld was porous in three places where it had to be ground and re-welded.

- O Later analysis showed the presence of high chromium content in the weld metal indicating a possible use of the wrong welding rods.

The weld-related events noted after plant operation, cool-down for system repair and heat-up to resume operation are described below.

Event M1, 7 September 1981

Sodium leakage through a crack running from the circumferential seam weld. Examination showed a pore in the weld seam at the point of starting the weld.

It was temporarily repaired by grinding out the cracks and welding over.

Event M2, 14 September 1981

Sodium leakage through a crack running from the circumferential seam weld. Examination showed a very small pore in the weld. There was no indication of this crack on the radiograph taken before repairing event M1, but it was just visible as a hairline on the radiograph after repairing M1.

While grinding out this crack (M2) a crack was seen in the seam weld, say, 50 mm long and 10 mm deep. This other crack was also ground out followed by filling with weld metal. The welding operation was preceeded by local preheating using a flame (acetylene torch) and followed by heat treatment again using an acetylene torch.

Event M3, 18 September 1982

This was a third crack running from the same seam weld. It was ground out and welded using the same procedure as for events M1, M2.

5.3 Regenerator Vessel, Event R1, 7 September 1982

Sodium leakage from a crack running from a circumferential seam weld that is made around the cylindrical part of the vessel near the bottom.

Examination has shown that there was a step of about 4 mm between the edges to be welded. Also the crack originated from the joining point of the two ends of the first weld-run in the root of the seam weld.

5.4 Thermal Cycling in Cold Tank

The designed method of operating the solar plant is such that hot sodium is injected daily, so far on average four times per operating day, into the cold storage tank. The cold storage tank at these times is at a temperature between about 240° C to 270° C.

When sodium leaving the receiver is at a temperature of less than 480° C, a valve automatically opens to send it to the cold tank; if it is higher than 480° C, it normally passes to the hot tank.

This occurs at the start of the day, when the system has to be warmed up. Sodium at temperatures up to 480° C is passed back to the cold tank for a period of between 20 and about 60 minutes. Also injection of hot sodium occurs during shut-down at the end of the day and when clouds pass over the heliostat field.

Since October 1981, there have been about 460 cycles and in total, say, 500 cycles. These are estimates and not derived by checking through all the record sheets.

The size and duration of these thermal cycles in different parts of the plant are not known with any precision. Thermal shocks will be greatest in pipework from the receiver to the cold tank with some modification as it passes through the top of the cold tank and finally into the sodium.

Some indication of temperature cycling has been obtained from thermocouples fitted on 20 September 1982, one alongside the sodium pipe where it passes through the top of the vessel and another outside the bottom of the tank near the stud under the sodium inlet pipe.

Records from these thermodcouples are available for four days: 22 to 25 September. They show temperature cycles on the inlet pipe up to 210° C and at the tank bottom of up to, say, 40° C with a maximum transient on the tank bottom of 4,5° C/minute.

5.5 Spilling Engine

The Spilling engine is a 6 cylinder reciprocating engine with all cylinders in line. There are 5 stages of steam pressure, the lowest having two cylinders in parallel. The top operating temperature required is 380° C and the highest pressure 100 bars, both within Spilling experiences but probably not both together as for the Almeria plant.

Specific design changes have had to be made to the high pressure cylinder. The initial re-design was to reduce the thermal capacity of the cylinder and to increase the size of the port for steam flow into the cylinder. The steam port was increased by changing its shape from round to rectangular; but on the next run, the piston rings broke due, it is concluded, to them catching the edge of the rectangular hole. The hole shape was changed to remedy this defect.

Other faults are ones that do not appear to have required design changes to the machine. However, it has been difficult to make an analysis of the history of operation of the machine because Interatom do not have an incident list nor detailed failure reports. The expert for the full period of operation had to base analysis on the following information:

a) letter 10 October 1982 from Spilling Consult AG to DFVLR
b) oral information from J. Hansen, Fichtner Consulting
c) flow sheet full load, CRS plant, V 3941-7, Spilling, 3.11.80
d) Interatom, SSPS Map No. 11, Start-up procedures, p. 90-95.

The enclosed incident list (Table I) was prepared from these sources. It contains 6 incidents of which three seem to have a clear origin. No. 2 was obviously caused by events outside the PCS system. The list shows three incidents of unknown origin and data does not appear to be available to enable identification of the cause of these incidents (1, 4 and 6). A written statement from the Spilling engineers is urgently needed. The discussion in the present report may be helpful.

6. DISCUSSION OF PAST DIFFICULTIES

6.1 Sodium Systems

The first problem is to answer two questions:

1.) Why were cracks present in the hardware?
2.) Why did these cracks propagate?

Crack presence can be reasonably explained. Weld design and welding practice led to defects that could not be machined away. In one particular weld design, for example, the shock plate with rails presented an extraordinarily difficult access problem to the welder attempting to weld the inner side of the rails to the cold storage tank bottom or to a machinist attempting to smooth the weld bead. An example of poor welding practice was the presence of annular gaps between unmelted weld rod and base material that could serve both as a storage site for NaOH caustic and as a stress raiser.

At first, the question of crack propagation seemed to have an obvious answer: thermal fatigue. Fractography, however, showed that the obvious answer was incorrect. All cracks observed propagated in a brittle manner - often along prior austenitic grain boundaries and mainly through the weld transverse to the weld axis. The fracture often extended through the heat-affected zone, finally blunting in the base material. Scanning Electron Miscroscope (SEM) studies showed no ductile regions and no evidence of striations. Cleavage regions and intergranular brittle fracture regions were strikingly, clearly shown.

Use of a cold tank made from ferritic steel is not a new technical venture. Tanks of similar material have been used as "dump" tanks for storing sodium for a number of applications; for example, the Prototype Fast Breeder in Scotland has such a tank that has been in use for many years with no problems. Sodium from steam generators has been "dumped" into it many times, following small leaks from steam/water to sodium, and the sodium is far from clean because the tank is used as a settling tank to partially clean the sodium.

Why, then, brittle crack propagation in this application? Possible reasons for raising the ductile to brittle transition temperature of the ferritic steel weldments and heat affected zones (HAZ) are listed below.

- O Hydrogen embrittlement of the weldment and HAZ
- O Temper embrittlement of the weldment and HAZ
- O Caustic embrittlement of the weldment and HAZ

These three types of embrittlement usually require stresses near the yield strength, an initial crack present longer than a critical length, and temperatures below 240^{o}C.

If hydrogen embrittlement is the cause of crack propagation, the source of the hydrogen is of interest. Three possible hydrogen sources are

- O Moisture present during welding, due to handling of electrodes by wet (sweaty) hands, improper electrode drying, moisture from high boiling-point NaOH solutions, or other, unknown source.

- O H present in the sodium due to a reaction between sodium and oil.
- O H present in the sodium due to a reaction with water or steam.

Unfortunately, none of the above sources could be eliminated as suspects. Perfectly spheroidal pores were observed in the first weld to fail, which could indicate moisture during welding. An incident did occur in which sodium poured on oil in the hot pump and this sodium was in contact, through flow lines, with the bulk of the sodium. Sodium/water reactions of a very small nature should be picked up as H readings on the gas chronomatograph. High readings of H were observed in December, 1981 over several vessels and then the chromatograph was inoperable during 1982, so preventing detection of very small water leaks into the sodium. Large leaks would register as gradually rising plugging temperatures in the plugging meter.

Thus, we cannot rule out hydrogen embrittlement.

Temper embrittlement of ferritic steels is a common phenomenon when certain heat chemistries are involved and the steel is held within a rather limited temperature range, usually around 400° C. The susceptible heat chemistries are best described by the Watnabe number. This number is defined as

$$(\text{Wt }\%\text{ Mn} + \text{Wt }\%\text{ Si})\ \ (\text{Wt }\%\text{ P} + \text{Wt }\%\text{ Sn})\ \text{X}\ 10^4$$

If the value is over 80, some increase in the ductile-to-brittle transition temperature (DBTT) is noted. When the value is over 200, DBTT values above 200° C can be expected. The base alloy in this study has a low Watnabe number well over 200. This type of embrittlement causes segregation of brittle phosphides in the prior austenite grain boundary but does not raise the hardness of the weldment. Two methods exist for establishing the presence of temper embrittlement.

- O An energy absorption vs temperature plot of the Charpy V-notch type would show the ductile to brittle transition temperature increased from below 0° C to the 200° C range.
- O Auger analysis of a specimen from the weld fractured inside the Auger device would show several atomic percent of P, Sn, Sb, or As at the fracture boundary.

Thus, unlike hydrogen embrittlement, the presence or absence of temper embrittlement can be proved (Later tests showed it not to be present).

Caustic embrittlement of the weldment and heat-affected zone is much rarer for ferritic steels than for austenitic, but it will occur if highly stressed steel is subjected to NaOH of a fairly limited concentration range for fairly long times. The regenerator vessel definitely had weld-associated cracks caused by caustic embrittlement so such conditions are a potential problem for this hardware. As far as we know, the initial crack could not have had caustic present, so another embrittlement phenomenon in addition to caustic cracking is strongly suspected (unless filling, emptying, and inadequately cleaning of the cold sodium storage vessel occured before the first failure). Once a leak has developed, contact with moist air will generate NaOH and so enable establishment of caustic cracking conditions on the outside of the vessel underneath the logging. The conditions for caustic cracking of these weldments are approximately those shown in the figure 3, but the concentration and temperature limits are not known. An additional parameter of critical importance is time to failure, which is usually many days for ferritic steels.

The temperature range for all the forms of brittle fracture is usually considered to be below 250° C, and the 270° C nominal operating temperature seemed a bit high to be giving all the brittle fracture cracks. We obtained a plot of the actual temperature that the cold storage tank had. We note that much of the time sodium temperatures below 240° C have been maintained.

The most important point to note is that very high stresses are needed to propagate all those fractures. Stress relief of the welds will eliminate the high residual stresses presently associated with the welds.

As far as the future is concerned, none of the proposals for the cold tank include the particular shock plate feature that has been the source of most difficulties. Particular points to consider in relation to future proposals for the cold tank are

- ability of the pipework and hot sodium distribution system inside the tank to meet thermal cycling conditions;
- avoidance of unacceptable thermal cycling on the tank;
- ability to fit and weld a new floor section. Cutting the old section out will inevitably disturb the floor - there is severe distortion from recent cutting of a square sample (ca 1/2 m^2).
    - Interatom have been asked to check a similar repair elsewhere;
- the need to stress relieve, allowing for
    - the need to cold work a floor piece to make it fit
    - inability to inspect the inside of the manhole weld

- desire to be overcautious;

- O should flanges be fitted to the manhole cover (and the regenerator)?
  - not necessary for operator access, cutting a weld instead is not a significant problem;
  - the need to weld and grind on the inside;
- O access, say, for an intrascope through one of the top penetrations, to enable quick internal viewing;
- O preheating of welds to 100^{o} - 150^{o} C.

Following from the past experience with this plant, it would be sensible to examine parts of the plant while it is non-operational and to check certain design features. Particular points identified before the review of Interatom proposals, Section 8, are

- O Interatom to check design of the hot storage tank that contains similar shock plates to the cold tank;
- O check welds in the cold tank for defects and cracks including the ferritic hot sodium inlet pipe, the transition weld and the thermal sleeve at its top.

6.2 Spilling PCS

There have been faults in three cylinders; one of them is specifically attributed to water hammer in the high pressure (No. 1) cylinder in September 1981 and no explanation has been given for failures in the other two cylinders; No. 6 cylinder in August 1981 and breakage of the eccentric rod of No. 3 cylinder in August 1982. The possibility that the basic cause of these faults in cylinders No. 3 and No. 6 was also due to water hammer cannot be ruled out, see Annex 2.

The design of the machine and its method of operation is such that during start-up, any steam and water leaking past non-return valves and condensing in the cold pipelines would pass to the cylinders. Also during commissioning of the re-heater systems, only the metal in contact with live steam becomes hot initially and there could be condensation on other metal that would then have to be drained.

In principle, there is a number of ways in which water could pass to the cylinders to cause damage. Such damage has to be avoided by designing pipe runs and drain lines to ensure that any water formed cannot pass to the cylinders. Additionally, maintenance and operation procedures have to be carefully defined and followed to ensure that the system functions as intended. There has not been time to investigate the detail of design, construction, operation and maintenance to check whether some changes should be made.

Otherwise, none of the faults to date with the Spilling engine are fundamental; there is no specific reason why it should not operate successfully in the future. However, it is extremely difficult to judge whether there will continue to be a number of time-wasting adjustments and minor modifications before it becomes a reliable machine.

Points to consider in forming a judgement are

- O detailed operator know-how
- O operator confidence
- O if necessary, reduce output
- O timescale for the project

Operating staff say that the "man from Spilling" tends to nurse the engine by regularly making minor adjustments. The operators do not yet appear to have a "feel" for the need for and how to make such adjustments. For any continued operation with the machine it would be essential to ensure that the "man from Spilling" continues to be on site until the operators were confident that he could leave.

In making a decision of this type, it is important to take into account the attitude of the operators. They are now familiar with the machine and seem to have more confidence in facing a future with it than with changing to deal with some other lesser known (to them) machine.

Opinions have been expressed that the machine "sounds to be much more comfortable" at less than full power and that at full power it "sounds like it is having to work too hard". This is a very subjective judgement, but if it is true and if it could be made a sound engineering judgement by those who really understand the machine, then it could be better for the plant as a whole to reduce power initially with the intention of increasing it as confidence grows. This would reduce steam flow to the Spilling engine, but the available energy would continue to be stored and be available for a longer running period of the Spilling engine, thus causing only a very small energy loss (few percent).

If the time scale is such that the project must be assumed to be completed at the end of 1983, then it is quite a significant gamble to change to another type of machine.

7. DISCUSSION OF INTERATOM PROPOSALS

Examination of the Interatom proposals in their document, "Concept for final solutions of CRS problems proposed by Interatom" dated 26 November 1982, included a full-day meeting between all members of the Experts Group and representatives of DFVLR, Interatom, VÖEST, and TÜV on 2 December 1982.

The main points relevant to future decisions that arose from the discussions are now summarized.

7.1 Cold Sodium Storage Tank

The Interatom proposal is to repair the existing tank. Supply action has been initiated to procure material for a new tank, should this be required.

The proposed repair to the tank bottom will remove the "shock plate" design features that have caused the series of leakage and repair problems in the past. In welding a new section into the tank bottom, the measure proposed by Interatom appear to be adequate to ensure an acceptable repair. Particular features are

- strengthening to avoid distortion by cutting out the large piece
- preheating
- use of experienced welders
- the joining of the vessel seam weld to the new weld is within recognized practice
- the welding operation can be made to meet existing codes and regulations in Germany.

Removal of the manhole "stud" removes from the vessel all metal associated with the previous weld defects and repair operations. Examination of the reasons for earlier failures, section 6.1., give confidence, that a satisfactory new closure weld can be made. The need to avoid artificial cracks by weld design is well understood and sensitivity to potential future causes of cracking will be significantly reduced by post-weld heat treatment. An important point to note is that this particular weld has to be made in the same way in the new vessel design proposed as an alternative by Interatom.

The alternative suggestion, not included in the Interatom proposals but with individual proponents, is to fit flanges to this manhole. This would have the technical advantage of

- enabling welding and inspection of both sides of the large diameter weld in the manhole

but normally such flanges are fitted to manholes providing access to the gas space above sodium in storage vessels. To use one in this particular application would present a liquid sodium surface to the flange joints with some surface movement and thermal cycling. The argument for better inspection of the weld is not considered to be sufficiently strong to recommend acceptance of flange joints for this particular technical reason. The flange joint would require a large diameter sealing ring backed by a seal weld, both within sodium handling experience. Also

- there is no significant operational advantage in using flanges, the time to cut off a weld would not be significant compared with the time to deal with the event requiring access;
- closing the flange joint could lead to more difficulties in ensuring a good closure than would a properly designed weld.

The proposed design of T-piece for the hot sodium inlet pipe should be satisfactory. The detailed design was not examined in detail and needs to be approved between the Project and Interatom staff. The Experts Group noted that, should it fail due to vibration or some other cause, it should not be difficult to insert an alternative design similar to the one to be used in the hot sodium storage tank.

Stress-relieving of the vessel is proposed by Interatom and it is clearly a sensible precaution to take in view of problems from the past. Even after a full and detailed examination there could be some elements of doubt about potential for any remaining highly stressed zones to become sources for crack generation. However, it should be noted that manufacturing codes relevant to this vessel and the proposed repairs do not call for stress relieving.

Care must be taken in the stress-relieving operation to ensure that unacceptable temperature distribution is not generated in the vessel. It is recommended and accepted by Interatom that

- an analysis of heat input rate and distribution related to thermal insulation and resulting temperature distribution should be made.

7.2 Regenerator Vessel

Interatom proposals for this vessel are to cut off and replace the bottom of the vessel, referred to as the manhole, and to stress-relieve the weld. VÖEST have said that they could stress-relieve the whole vessel if it were necessary to do so.

If there had been evidence of brittle type failures that could occur in the whole vessel, then there would have been a very strong incentive to heat-treat the whole vessel. However, the brittle type failures observed to date have been explained by caustic corrosion cracking on the inside of the manhole weld and that will be removed for the repair. If no other reasons are found to suspect potential for brittle type failures elsewhere in the vessel, then the strong incentive to heat-treat the vessel is removed.

If the vessel were to be heat-treated, then it would be necessary to first clean the vessel, and that is an operation that could cause problems in that it introduces moisture into the vessel (It was later decided to clean the vessel by distilling out sodium by generating a vacuum in the vessel). Since there has not been an assessment of what would be involved in heat-treating the vessel and since there is a desire to avoid cleaning, the decision as to whether or not to heat-treat should be made after

- O examining how to heat-treat
- O assessing potential for brittle crack growth
- O completing examination of the vessel for cracks as far as is practicable.

Definition of welding procedures must obviously take into account the presence of sodium on the inside surfaces of the vessel.

7.3 Hot Sodium Storage Tank

Interatom proposals for the hot sodium storage tank are

- O to assess the potential for failure of the "shock plates" on the bottom of the vessel, similar to those in the cold sodium tank;
- O to inspect the outside of the bottom of the tank by crack detection methods, ultrasonic;
- O to install a flow distributor that would avoid direct impact of sodium temperature pulses on the "shock plates".

This is an austenitic steel vessel and its operation causes less thermal cycling on the shock plates than in the case of the cold storage tank. There have been no sodium leakages or failures in this tank.

VÖEST and Interatom have made a thermal and stress cycling analysis that inevitably must be only an estimate to give a feel for the present position, in particular because we do not know whether there are any cracks in the "shock" plate feature from manufacture. All that can reasonably be deduced from the calculation is that if there were no cracks, then there could be a comfortable margin to failure, whereas if there were cracks, then there could be little margin to failure.

In the circumstances, Interatom have made an acceptable proposition, but it must be recognized that acceptance is a matter of judgement. The proposition agreed is

- to inspect the tank bottom for cracks recognizing the limitation that any cracks near the rails of the "shock" plates are unlikely to be detected;
- minimize further shocking of "shock" plates by fitting the flow distributor and optimizing the method of operation of the plant to minimize such shocks both in amplitude and frequency.

The design of flow distributor appears to be acceptable and, if it failed for any reason, it could be replaced. Agreement on the detail of design must be negotiated between the Project and Interatom.

7.4 Power Conversion System, PCS

The relative merit(s) of other power conversion systems had been the subject of a previous Expert Group examination and in their proposals Interatom do not recommend installation of a new or used turbine. Instead they recommend retaining the Spilling PCS and offer the maintenance and repair free of charge to the end of 1983.

The longer time scale for installation and the higher costs are factors for the Project to consider in deciding whether to change from the Spilling PCS at this stage.

From a technical point of view, the use of turbines is less satisfactory than the Spilling PCS because of their lower steam efficiency, energy output, say, 76 - 78 % of that from the Spilling system. The technical incentive to change rests solely on the degree of confidence in continuing with the Spilling system balanced against whether or not there could be difficulties with turbine systems.

The technical choice between the two systems is clearly a matter of technical judgement. The judgement by the Experts Group is that the Spilling PCS should be retained. Points relevant to that decision concerning the Spilling PCS are adequately described in earlier sections and Annex 2 and recommendations made in Section 8. Specific points concerning the turbine alternative are also made in earlier sections and Section 8. They include

- some uncertainty about the overhauled GE turbine because it has been in store for about 2 years
- no guarantee with that machine
- operator attitudes and recognition that changing to a new system may identify new problems as a whole in the plant that could cause future technical difficulties.

The proposal by Interatom to install an oil-fired heater would have the technical merit of maintaining more continued use of the Spilling CRS but it would still be closed down overnight. The energy costs would be high, approximately 32 Pfennig/kWh for the oil only, compared to 6-10 Pfennig/kWh for normal electricity generation costs, so there would be no economic advantage. Whether or not the Project wishes to incorporate the unit as part of plant demonstration, must be a Project decision. If it were considered to be worthwhile, then it would be prudent to delay installation until after the present problems are overcome.

8. RECOMMENDATIONS

In writing this report and compiling the following recommendations, we have commented upon all the aspects of the plant that have occured to us as being possibly relevant to ensuring satisfactory repairs and future operation of the plant. The degree of detail presented may tend to give the impression that there is considerable uncertainty about the viability of the plant. This is not the case; providing that the repairs are made as planned, the plant should be successful.

The detailed recommendations are to some extent a checklist of points to note in planning repair and as guidance for future operation. They are ones that we feel confident that the designers and operators are aware of but that warrant comment in an investigation of this type.

The particular technical point of most concern is the finding of brittle fractures in the regenerator and cold sodium storage tank. Examination to date identifies at least one crack with caustic corrosion and all the cracks are in weld zones to be cut out during repairs. It is essential to ensure that established welding procedures and practice for handling sodium are applied in the future to avoid recurrence of this type of failure.

8.1 Cold Sodium Tank

Provided that new information obtained from continuing detailed inspection of the tank and of metallurgical specimens taken from the tank are consistent with the conclusions drawn from existing information

- O we do not disagree with the Interatom proposal to repair the tank.

Particular care must be taken in repairing the tank bottom to ensure that experienced welders are employed; they will be provided by VÖEST, the vessel manufacturers, and that specified procedures for controlling welding rod quality are maintained.

Although there is a possibility that full stress-relieving of the vessel after repair may cause some distortion of the vessel, it is difficult to conceive that this would be sufficient to prevent its operational use. To ensure that there are no high stress points that could have retained moisture and to make the vessel less susceptible to cracking in the future, it is recommended that

- O the vessel should be stress-relieved as proposed by Interatom;
- O to optimize the operation, an analysis should be made of temperature distribution related to heat input rate and thermal insulation on the outside of the tank.

The manhole closure should be designed

- O to avoid artificial cracks that could become zones of future crack growth initiation.

To do so by welding, as proposed by Interatom, necessitates ensuring that the weld design allows full penetration with avoidance of such cracks when only welded from the outside.

- O Such a weld should be heat-treated.

The alternative of fitting flanges is not preferred because such a flange joint is larger than normally used in contact with liquid sodium and could become a source of difficulty in operation since the large diameter seal ring should seal adequately to prevent sodium reaching the seal weld that is a necessary feature of this type of joint. Large diameter manhole ports with flanges are normally fitted to give access to gas spaces above the sodium level. There is no significant access advantage in that the time required to cut off the weld for access would be small compared with dealing with an event that has required access.

The exact design of the proposed new hot sodium inlet distributor needs to be agreed between Interatom and the Project staff,

- O the principle of the design is acceptable
- O if for any reason it breaks, there is potential to replace it by a design similar to that proposed for the hot tank.

8.2 Regenerator Vessel

The Interatom proposal to repair the regenerator vessel does not include cleaning the vessel and requires welding of a new end on the bottom of the vessel. These proposals are acceptable providing

- O a careful examination is made to ensure that there is no caustic corrosion cracking in the outside surfaces previously in contact with leaking sodium and reasonably within the vessel above the weld zone;
- O the weld is properly designed to ensure that there are no artificial cracks.

Comments made in section 8.1. concerning the choice of flanges also apply to the choice of flanges for this end feature.

Interatom has proposed to heat-treat the weld and VÖEST has said that, if necessary, they could heat-treat the vessel. However, a technical assessment of what would be involved to perform this heat treatment has not been made. The only new weld would be that at the bottom of the vessel, which would serve as the vessel closure weld. Stress-relieving techniques that involve internally heating the vessel with installed equipment cannot be used on a closure weld.

The purpose of heat-treating the whole vessel would be to relieve stresses currently in the vessel. As far as potential for future cracking and leaks is concerned, it would be prudent to stress-relieve. However, if (and only if) there is no reason to suspect cracking in the vessel (from current metallurgical examinations) and recognizing that the vessel would have to be cleaned first, then it would be acceptable to not stress-relieve the vessel (It was later decided to clean the vessel by vacuum distillation). Whether or not stress-relieving should be done should be decided after

- O evaluation of the problems associated with stress-relieving
- O completion of assessment of potential for existence and propagation of cracks in the vessel.

When welding the new bottom to the vessel, it should be recognized that the surfaces of the vessel are still coated with a layer of sodium (Not after vacuum distillation).

The technical recommendation for this vessel has been more difficult to arrive at than for the other vessels because of the presence of sodium, that may be contaminated, and the prior experience of caustic cracking (Alleviated by vacuum distillation).

8.3 Hot Sodium Storage Tank

There is uncertainty in judging the state of the bottom of this tank in that stress and thermal cycling calculations indicate a comfortable margin to failure, if there were no initial cracks, and a low margin, if there were. We do not know whether there were any initial cracks.

There have been no failures of the tank. In the circumstances it is reasonable to plan to continue operation with this vessel after satisfactory implementation of Interatom proposals

- to inspect the underside of the bottom of the vessel for cracks near the "shock" plates;
- to reduce thermal cycling on the "shock" plates by fitting a flow distributor;
- to reduce thermal cycling of the "shock" plates by optimizing plant operation.

The design of the flow distributor appears to be satisfactory. Detailed design would be negotiated between the Project and Interatom.

8.4 Sodium System Design and Operation

While discussing the system as a whole with designers, who have been involved with component manufacture, the general impression was gained that there was not a good understanding of the thermal shocks that could arise from the way in which the system was designed to be operated.

- It is advisable to make some re-examination of the system to identify the magnitude and frequency of these shocks and the places of most concern, or interest, in the plant. This would almost certainly lead to the need for additional thermocouples on pipework and on some components.

Particular points to consider, if there are still doubts related to earlier design intent, are

- The temperature variations observed during the transient of passage of a cloud indicate temperature cycling of part of the metal tubes in the receiver. The amplitude of that cycling and its frequency should be checked against thermal cycling properties of the tubes of this type to ensure, that fatigue failure could not occur in the near future.

It seems to be unlikely that transients now observed were covered by the initial design specification or specifically taken into account in design.

The steam generator receives temperature transients while cooling down because temperatures falling in the outlet pipeline are used to indicate cold (240^{o} C) sodium flow into the steam generator. This is to avoid freezing of sodium in the pipes.

The design of the steam generator is not based on a requirement to accept frequent temperature cycling and it is prudent to minimize such cycles.

- O Options for change could be to trace heat pipework and/or modify the method for controlling this operation.

Although the steam generator vessel has been stress-relieved, the tubes have not, and there is a number of welds in the tubes. For reactor applications, all designers and operators are sensitive about potential for failure of welds separating sodium and water, so although technical data on the welds may show them to be satisfactory, it would be prudent to avoid unnecessary thermal cycling.

- O It is important to ensure that the instrument for measuring hydrogen content in sodium is operational, since this is the only method for identifying a small leak between steam/water and sodium in the steam generator.

8.5 Metallurgical Investigations

The following investigations would help Interatom to make decisions that are still pending:

- O Auger analysis of weldment and heat-affected zone (HAZ) to determine P, Sn, Sb and As content of surfaces from fractures occurring inside the Auger apparatus.

- O Measurements of the ductile to brittle transition temperature of the weld alloy cut from tank bottom.
- O Measurement of time to cracking of a circular weld patch (on a coupon of the base material using the weld alloy) when immersed in dilute NaOH that is allowed to boil at 125^{o} C with and without a watch glass on top of a beaker. Oxygen content can be important. Repeat at different temperatures.

  Each experiment may last weeks. Repeat with stress-relieved material.
- O Induce hydrogen electrolytically into circular weld patch as above. Note failure mode. Repeat with stress-relieved material.
- O Get a fracture mechanics specialist to do experiments on cast form of weld rod after appropriate time temperature exposure.

8.6 Choice of PCS

Comment is made in section 6.2. on potential for further difficulties with the Spilling engine. Whether or not there will be significant future problems is difficult to judge. Past technical problems have identified faults that have been remedied and, subject to satisfactory resolution of problem associated with drainage (8.6.), there is no specifically known technical reason why there should be further failures.

To change now to a steam turbine would incur significant additional cost (approximately 3 MDM plus cost of construction and modification of condensate system) and a long time delay (approximetaly 11 months). If the reconditioned GE turbine were used, there would be some uncertainties and disadvantages:

- O it has been in store for 2 years; will it still be in good working order?
- O There would be no guarantee associated with purchase.

If a new machine were purchased, the costs would be higher and timescale longer. For all turbine alternatives there is the disadvantage that there would be

- O lower plant output, about 76-78 % compared with the Spilling engine.

The balance of judgement is in favour of continuing with the Spilling engine. However, because of comments referred to in 6.2., it is recommended that the engine should be operated at about 80 % of full design load until there is complete confidence in its reliability, and then consideration could be given to increasing power. This would not cause total plant energy production to drop. It would still be higher than that from a turbine, because excess receiver heat could be stored in the sodium hot tank and passed to the engine when the receiver is not receiving solar heat. The total energy production has not been calculated, but it would probably be only a few percent less than the design energy production.

From the Interatom report it seems obvious that the interconnection to the DCS is not a reasonable alternative.

8.7 Spilling PCS

The following rather detailed recommendations are made, partly to improve understanding of experience to date, and partly to assist in ensuring and good operation in the future.

8.7.1 Paperwork

- O Spilling should establish with Interatom a complete indicident report-list that mentions for each failure the findings, investigations and probable relevant facts. Any further incident should be added in the same style; especially incident 4 should be explained.
- O Interatom should calculate that lowest possible pressures at the heater during by-pass operation. Lower pressures from the by-pass can avoid excess steam losses via the drains in the bleed lines. See 8.6.2.
- O Spilling should give detailed report describing draining of the re-heat system and the bleed lines before engine start-up. They should state whether or not condensing water is running into the slide valve or into the cylinders. Experience from similar arrangements should be stated.

8.7.2. Modifications

- O A drain pot would be useful at each bleed line, just beside the engine head (lowest point!), and at the lowest point of the reheaters, or in the lowest pipe coming out from the reheater. Also there should be remote controlled drain valves, leading to the flash tank.

- When the by-pass is operating during start-up, the drains on the engine side of the non-return valves should be left open, until the heaters receive steam from the engine and the by-pass is shut.
- Within 15 minutes after closing of the non-return valves in the bleed lines, the drains in the bleed lines must open.

8.7.3. Operation

- Spilling should be on Site to continously advise on operation of the complete PCS, until the operation team is fully familiar with the system.
- Spilling should define requirements for regular preventive maintenance and advise the operation team.
- During each start-up and shut-down, the sequence of events should be noted in a logbook.
- Check every two weeks:
  - function of non-return valves
  - function of drain valves
  - function of steam traps (cleaning)
  - heater water levels.

8.8 Addition of Oil Fired Heater

Addition of the oil-fired heater proposed by Interatom would increase the technical complexity of the plant by adding an additional unit with its control system and by requiring modifications to overall plant control to enable change over from solar to oil heating. These technical requirements are practicable and they do not necessitate becoming involved in any new type of novel or untried engineering. However, it would be necessary to ensure that change-over procedures would not introduce new short-term transients that would increase the hazard to existing equipment.

- Although technically practicable, it is not recommended that the complexity of the plant should be unnecessarily increased at a time when serious problems in the sodium system still have to be overcome and confidence established in the Spilling PCS. The operator should deal with these problems and develop confidence in the system as a whole before adding the proposed new feature.

Whether or not it should be added to enhance the overall value of the Project is for the Project to decide. It may be judged by the Project to add to the value of the plant as a demonstration plant with a low additional capital cost, but the price of energy produced would be high. See section 7. If it is to be fitted, then it would be sensible to phase its installation to be after a reasonable period of satisfactory operation of the plant.

ANNEX 1

Comment on Spilling PCS

General considerations concerning troubles of unknown origin in the steam plants.

The experience with steam turbines of all sizes shows that backflow of water or cold steam is often the origin of severe damage.

APC 1972 Turbine water damage prevention - K. Reinhard
ASME Standard No. T W D P S, July 1972

These incidents leave no indication of what happened within seconds. Only temperature registration, a detailed knowledge of the plant, and the operators' logbook can give hints for an investigation.

Some of the BBC design rules against this danger are:

- All feed heaters are placed at a lower level than the turbine.
- Under the turbine no drain traps, only pneumatically operated valves, leading to a flash tank. In industrial plants, floating steam traps are now accepted. They need regular maintenance or cleaning inspections.
- The lowest point of the bleed line between turbine and the non-return valve needs a power assisted start-up drain valve, going into the flash tank.
- The start-up drain closes only when the bleed line has a steady flow from the engine to the heater.
- Non-return valves need regular maintenance inspections.

Application of the BBC design rules to the PCS:

According to the available information, some of these rules are not applied in the PCS. Mr. J. Hansen stated that the non-return valves had no known failure due to sticking, but there is no regular maintenance defined to minimize the danger of sticking.

The actual plant in Almeria has approximately the following levels in the bleed system:

- Engine head assumed 0 m
- Non-return valves, gate valve + 2,5 m
- By-pass into bleed line + 2,3 m
- Heater steam inlet approximately 0 m

The enclosed sketch, Figure 5, shows this arrangement. The information was phoned by Mr. Pescatore in Almeria. He could not find drains on the engine side, but the insulation makes checks extremely difficult.

Plants with this arrangement can only run satisfactorily with special precautions. Very important is the consideration of the start-up by-pass into the three feed heaters. This by-pass produces full load pressures in the heaters, independently of the load on the steam engine! The cold steam engine before the start-up must be able to accept cold vapor leaking through the non-return valves. This vapor condenses in the pipe and runs into the engine, into the slide-valve of the next lower cylinder, unless it is prevented from doing so by fitting drains.

The condensate pouring into the engine could wipe the oil off and lead to corrosion or decay. After start-up, the piston rings may break.

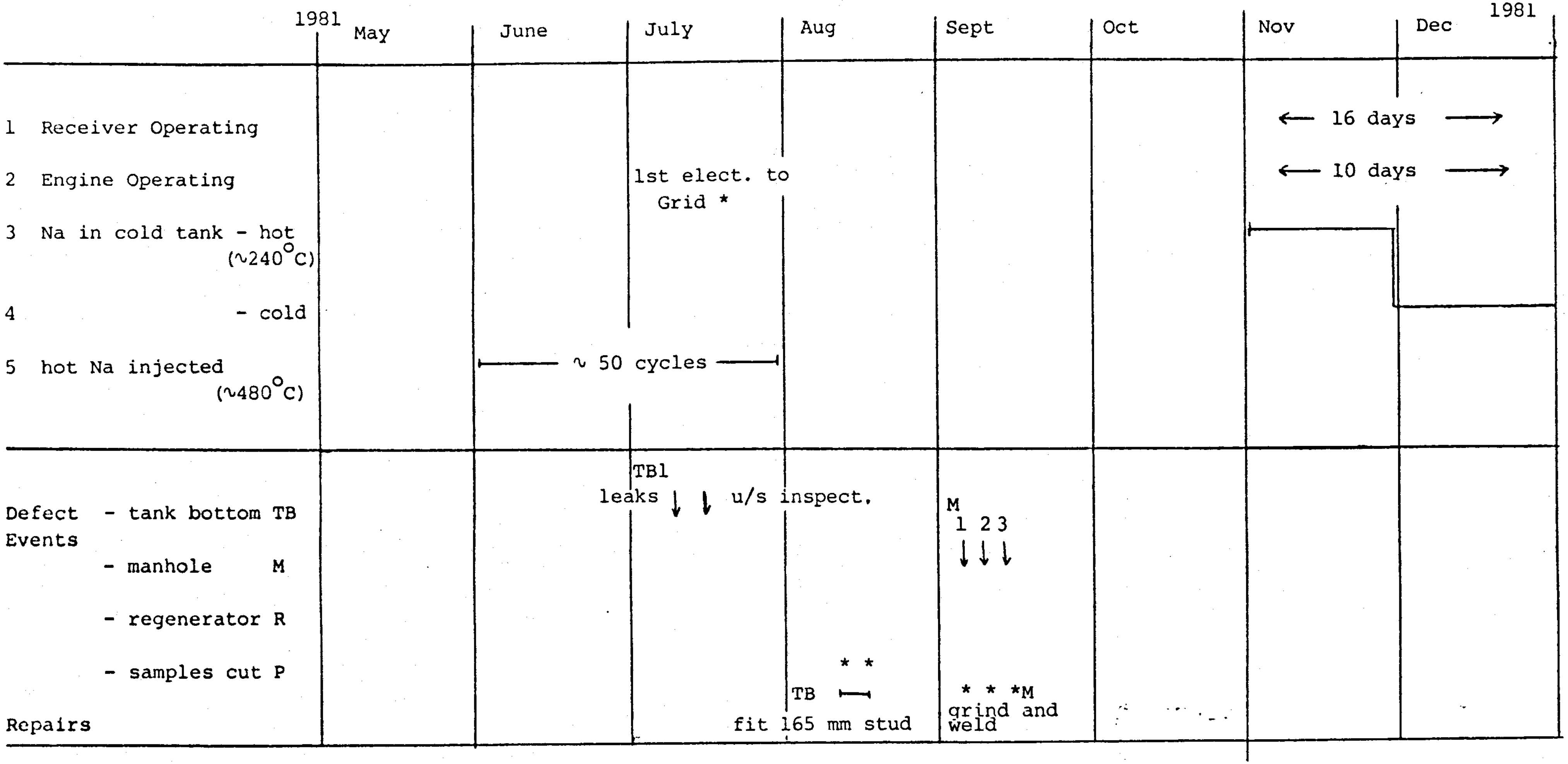
A similar condensate problem may exist around the re-heaters. The secondary side produces condensate (on cold start-up), but where it goes to is not known. Spilling should clarify the location of the sink for this condensate, see incident 4 of Table I.

Methods to keep the start-up condensate away from the engine:

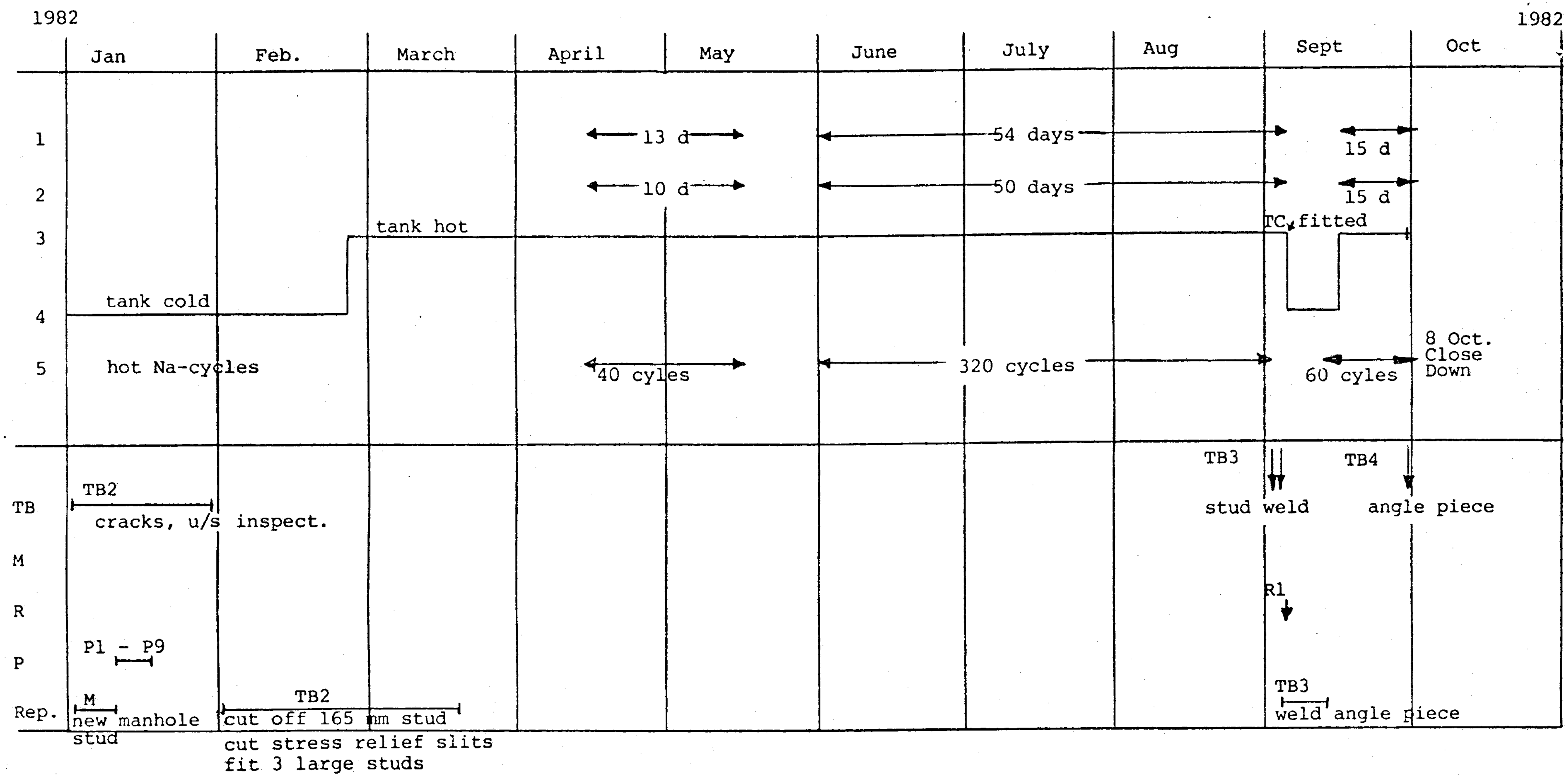
a) Close the bleed line gate valves during start-up. This seems to be a solution, but there is a danger of water hammer. Water may collect between the non-return valve and the gate valve. When the gate valve is opened before full power on the engine is reached, the by-pass blows this water into the engine. A drain with an orifice from the intermediate space could avoid the problem. A more reliable solution is b).

b) Bleed line gate valves never closed. All bleed-line-lowest points and the lowest point of the re-heaters to be fitted with remote controlled drain valves. These valves must be open when the by-pass is in operation, until the steam engine supplies steam to the feed-heaters. The drain must be the sink of a drain pot in the lower half of the pipes.

c) Condensate from re-heater. Drains according to b) should also be fitted to the secondary side of the re-heater.



Schedule of Events 1981



Schedule of Events 1982

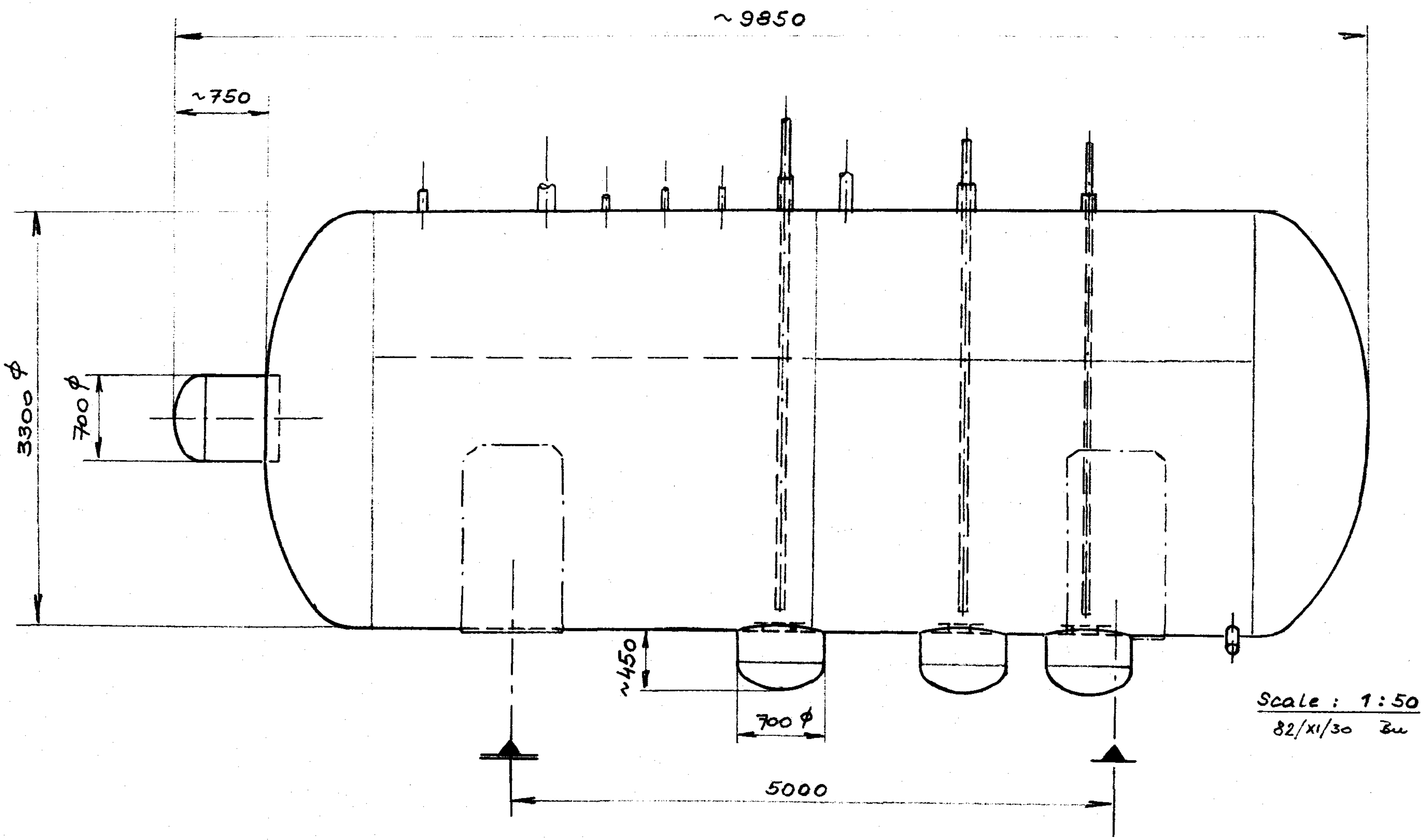


Figure 1 : COLD SODIUM - STORAGE VESSEL

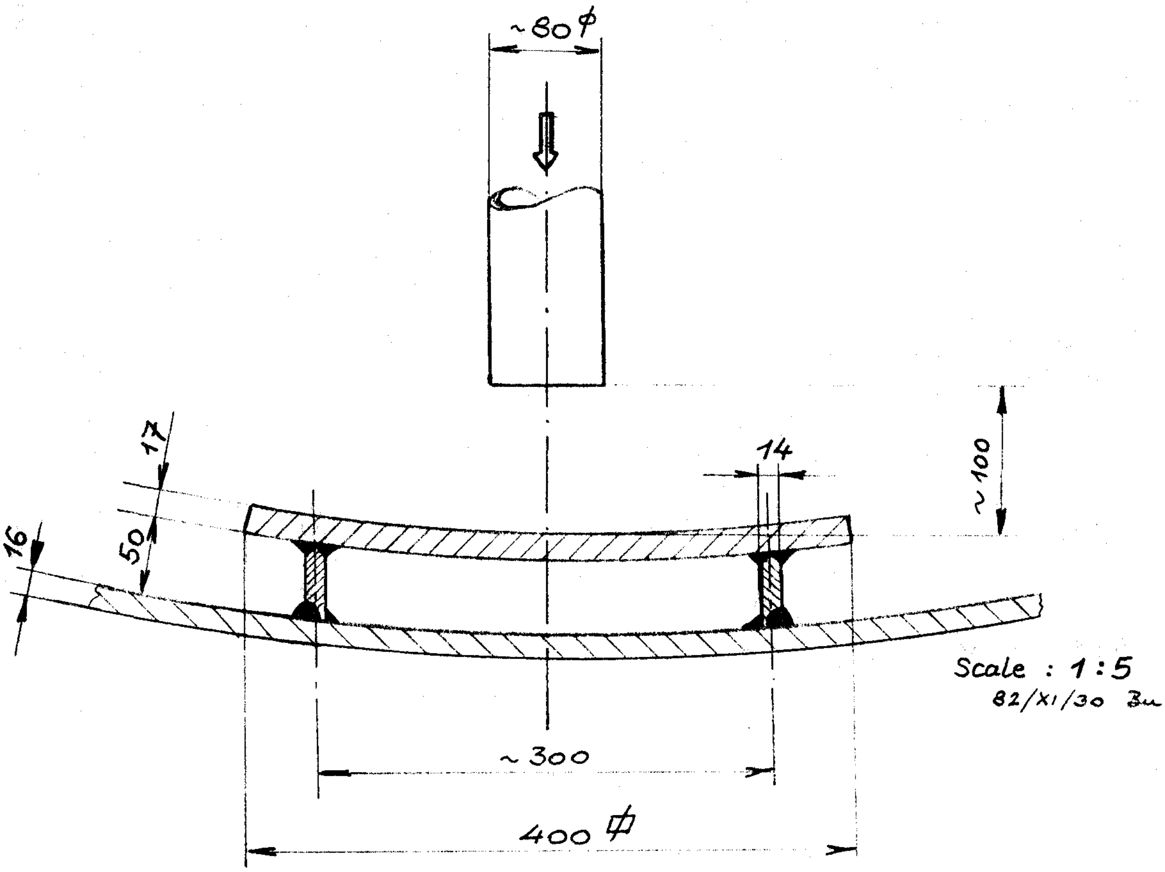


Figure 2 : SHOCK PLATE IN VESSEL

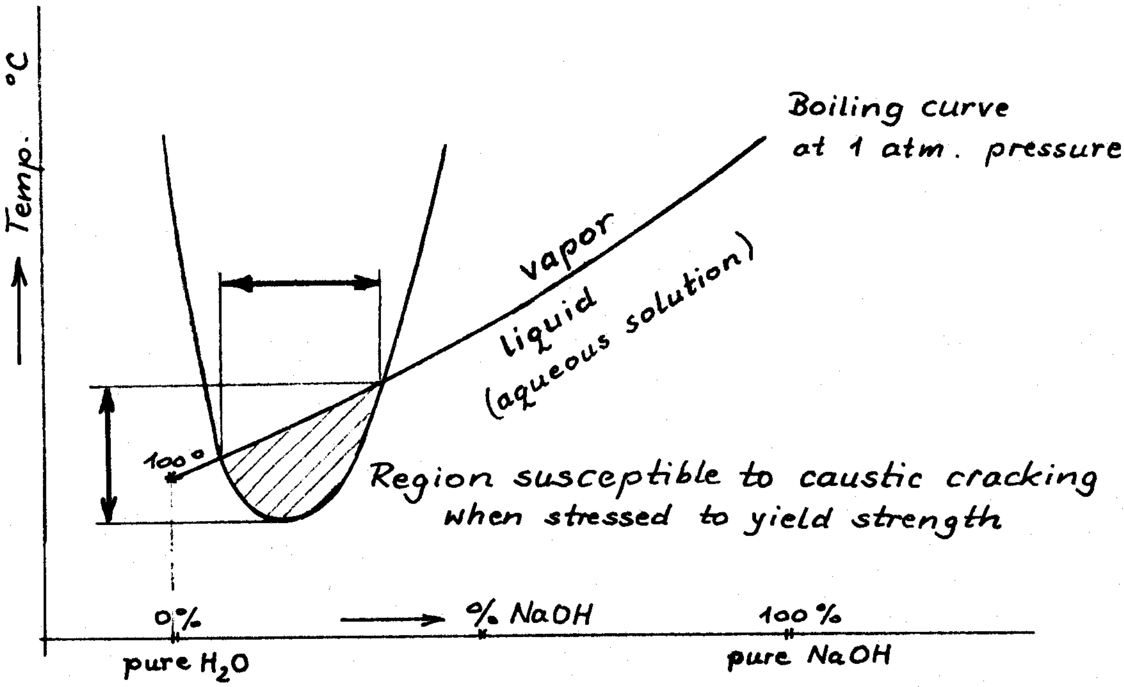
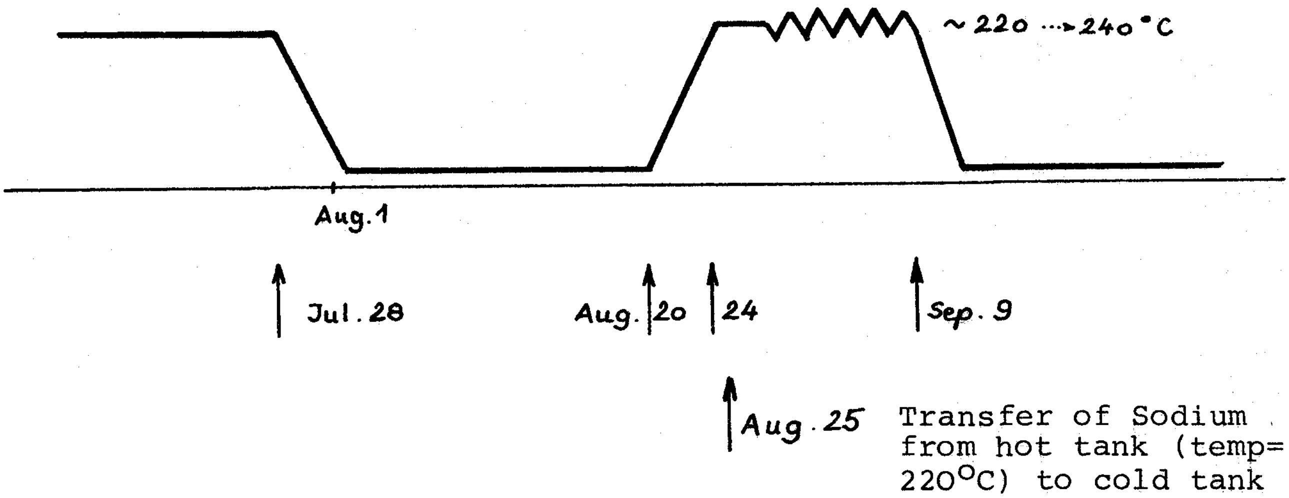


Figure 3 : CAUSTIC CRACKING OF FERRITIC STEEL

Lines with heavy arrows show an example of temperature range and concentration range for caustic cracking

Operation Period 28.7.1981 - 7.9.1981 +)



Operation Period 1.4.1982 - End of May 1982 ++)

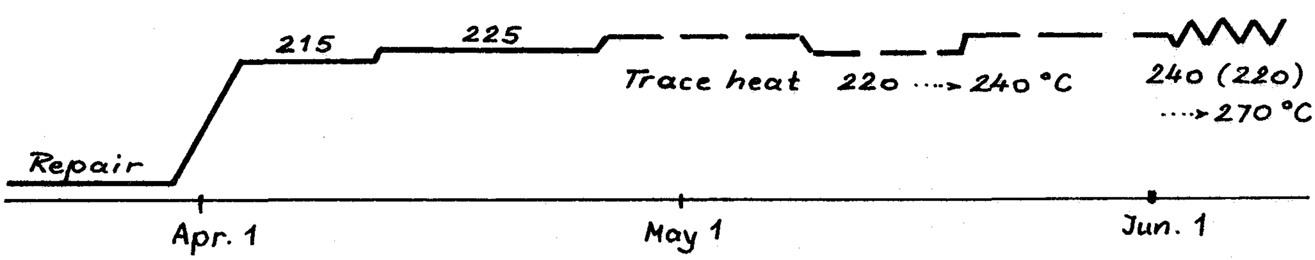


Figure 4 : COLD SODIUM TANK TEMPERATURES

+) Data from Interatom, Mr. Stahl

++) Data from Almeria, Mr. heintzelmann

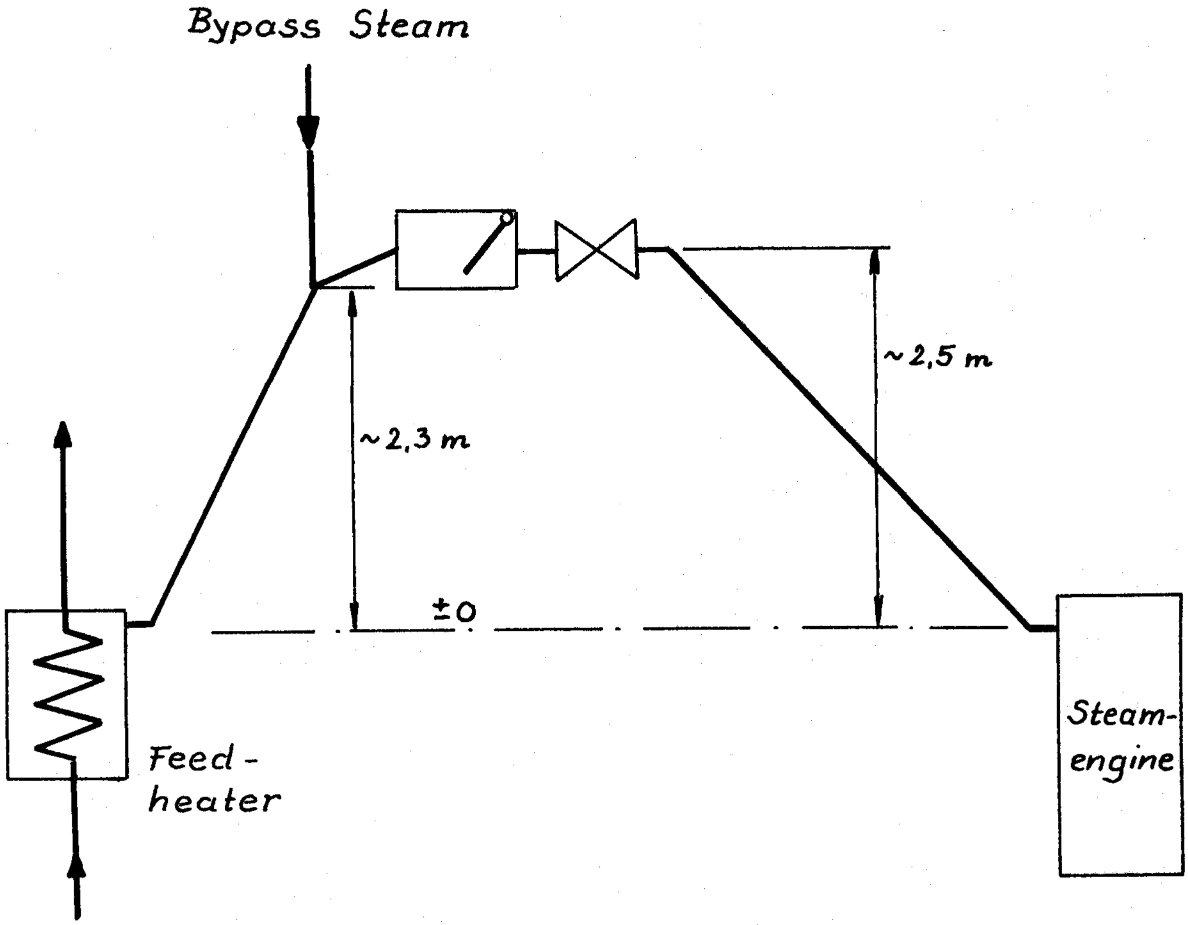


Figure 5 : BLEED LINE LEVELS , SPILLING PCS

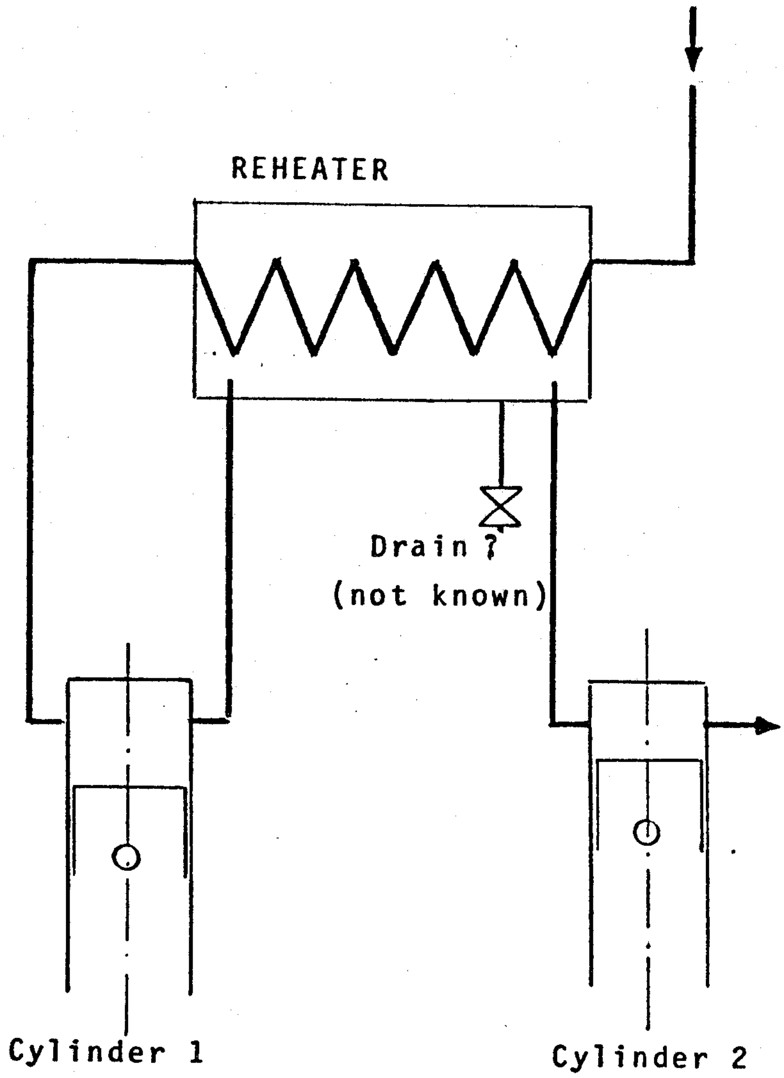


Figure 6. : FIRST REHEATER, SPILLING POWER CONV. SYSTEM
ALMERIA PLANT

Nr.	Description of incident and repair period.		Comments and origin	Explanation of origin	clea:
Event 1.	30. - 31.8.81	Dismantling slide-valve rings, slide-valve liner cylinder 6 damaged	Origin might be water from bleed line going to deaerater.	unknown	no
	1. - 2.9.81	Waiting time, paying duty on spare parts			
	3.9.81	installation of the valve liner and the slide-valve rings			
2.	22. - 24.9.81	examination of the disturbance, order and delivery of the spare parts	Water hammer of the motor through blockage of the high pressure drainage	During inauguration the danger of water hammer was indicated. The operator was asked to run on! Origin outside PCS.	yes
	25. - 5.10.81	waiting time to get the parts for the steam motor through the customs.			
	6. - 7.10.81	Reassembly of the cylinder			
3.	11. - 15.10.81	Breakdown of the cylinder oil pump	The 100 bar cylinder oil pump construction, tried in the past, was the product of the firm Bosch. Since Bosch has closed down their lubrication pump department, it was no more possible to go back to this construction. The designed substitute pump of a special Swiss firm was fitted out with parts which could not withstand the cylinder oil because of the high viscosity.	The comment gives no explanation why the new pump is better. But it runs ok.	yes
1982 4.	21. - 25.6.82	Dismantling of the HP cylinder, finding out that slide-valve ring was broken, liner was not round, reassembly	Delay or Seizure of the high pressure cylinder Scale from live steam piping or slight water hammer ?	unknown	no
	26. - 27.6.82	by the following test run, it was found out that the damages were greater than supposed at first			
	28.6. - 13.7.82	Exchange of the high pressure cylinder			
5.	6. - 9.8.82	Breakage of the governor driving gear	The gear got a blow by the disturbance 4 (seizing of the slide in the slide-valve liner) which resulted in cracks and later on led to breakage of the gear	Probably the disturbance 2, water hammer, was more decisive.	yes ?
6.	16. - 18.8.82	Breakage of the eccentric rod of cylinder 3	Origin might be water from bleed line going to highest feed heater.	unknown	no

TABLE I: INCIDENTS PCS

SSPS	IEA – SSPS PROJECT CRS	INTERATOM INTERNATIONALE ATOMREAKTORBAU GMBH

Nov. 26th, 1982

CONCEPT FOR FINAL SOLUTIONS OF CRS PROBLEMS PROPOSED BY INTERATOM

1192/10 79/2 (SSPS 009/4000/B)

List of Contents

0 Introduction

As a result of the 20th EC-meeting on October 22/23, 1982 INTERATOM has been asked to propose a complete and final solution of the existing CRS problems (SHTS leakages, PCS malfunctions) to be decided on at the next EC-meeting.

The following chapters include the solutions which can be offered by INTERATOM.

The content of this paper is structed in two main parts:

I Sodium Vessels
II Power Conversion System

which include the results of evaluations, investigations and modifications as well as detailed technical work programs incl. time schedules.

This paper shall be the basis of the discussion of the involved experts and can be completed if necessary. Further explanations can be given by the project management as well as specialists of INTERATOM on request.

J. Floss D. Stahl

CHAPTER I

SODIUM VESSELS

Chapter I.I

Evaluation of Concepts for the Sodium Vessels

Prepared by: INTERATOM
TVS-No.: 129646
Date: 82-11-25
Revision: 0
Approved by:

Contents

1 Cold Storage Vessel LK01 BB01

1.1 Evaluation of the problem and possible solutions

1.1.1 Evaluation of the problem

Since the first detection of leakages at the cold storage vessel on July 28, 1981 (see appendix 1) detailed investigations have started to analyse the reasons of the failure. Unfortunatly their always hase been a great disadvantage with respect to this investigations

- the small amount of material samples available
- the impossibility to inspect the vessel from inside.

Nevertheless all experts involved have agreed that the two different leakage areas of the storage vessel are of quite different nature so that the reasons for the failures have been summarised in the final report of the Operating Agent (Sodium Leakage at the SSPS-CRS Cold Storage Tank, Doc. No. R 68/82 WB, dated 11th August 1982) as the following conclusions:

"- No final explanation could be found for the defect baffle plate area ... It can be stated, that high residual stresses during the fabrication process caused the defects ... however, stress corrosion could be existing - even with little likelihood - and should not be excluded ...
The defects in the manhole stud have been caused by improper fabrication processes and by inadequate welding procedures ...

- The repair measures taken at the vessel's bottom could not be fully satisfactory.
  The solution chosen had to be a compromise that takes the time available for doing the job and the specialties of the sodium system into account ...

- As far as the manhole stud is concerned, it can be assumed, that after the repair it will be as good as a new and carefully fabricated vessel ..."

It should be added that INTERATOM's explanation for the failure of the baffle plate aera included the superimposing of the internal stresses of the weld seams by periodically changing loads and temperatures during operation.

Without anticipating the presently running investigations on the baffle plate aera (including the inspection of the total internal surface of the vessel) the effects of cyclic temperature changes caused by the solar specific operational conditions of the system seems to have caused a significant fatique of the material in addition to the already existing primary and secondary stresses due to internal pressure and residual weld stresses.

1.1.2 Possible solutions

In the first stage of the evaluation procedure to solve the problems concering the storage vessel 11 different solutions have been investigated (see appendix 2).

After the extensive discussions with the Operating Agent during the last weeks only two solutions have been isolated to be realized if necessary

- the repair of the existing cold storage vessel or
- the fabrication of a new cold storage vessel.

The following paragraphs will therefore only deal with these two possibilities.

1.2 Repair of the existing cold storage vessel

After a very complicated procedure to drain and clean the Sodium vessel which has already been performed as preparation of the possible repair the cold storage is now in a condition that standard repair measures can be applied.

Assuming that the investigations of the material samples which has been extracted from the damaged parts as well as the inside inspection of the vessel confirme the technical entirety of the vessel the following repair methods shall be applied:

- cutting-out the damaged part of the vessel wall (appr. 4.5 x 1.5 m) in the lower aera and replacing it by a new plate (see appendix 3)

- Modification of the outlet part of the internal down comer pipes to improve mixing of incoming sodium avoiding mostly thermal effects on vessel wall (see appendix 4)

- complete stress relieving heat treatment of the vessel.

The detailed repair program can be seen in chapter I.II.I.

Further modifications of the vessel e. g. a weld edge flange at the manhole or draining pipes at the vessel bottom cannot be recommended.

With respect to probable inside inspection procedures of the vessel the extended cleaning procedure (as demonstrated) is an unavoidable supposion any way. Thus an inside inspection is not to be recommended reasonably.

Regarding the welding of the manhole bottom experts do not expect an improvement of this part by using a complicated weld edge flange because state-of-the-art welding technique ensure a highly qualified weld connection in the originally specified way (see chapter I.II.I). The US-test of the complete welding area at the manhole which has been performed in the last week did not indicate any failure which confirmes the quality of the repair from Jan. 1982. It should be noted that the fabrications of such a flange will extend the repair time for about 2 months which is not yet considered in the attached time schedules.

1.3 Fabrication and Installation of a new storage vessel

As a second solution the fabrication and installation of a complete new vessel has already begun. The necessary material ordering has been initiated to spare procurement time.

The fabrication of a new vessel will be the applicable solution if the presently running investigations (material analysis, inside inspection) do not confirme the technical entirety of the vessel which would be the fact if comparable damages are found in any area beside the known one.

The detailed fabrication and installation program is described in chapter I.II.I. The time schedule attached to this document indicates a total time period of appr. 11 months including the installation of the new vessel.

The identical improvements of design as applied to the repair concept (see para 1.2) will be realised. In addition the manufacturer has increased the wall thickness to 18 mm. The material (15 Mo 3) will not be changed due to technical reasons.

2 Regenerating Vessel

2.1 Evaluation of the problem and possible solution

The failure at the weld seams of the manhole bottom seems to be identical with those of the manhole of the cold storage vessel and has been caused by a fabrication failure.

The first inspection of the material sample which has taken out shows clearly the reasons of the crack in a poorly welded part of the seam (see also chapter I.III.II).

In conformity with the solution which has been applied to the cold storage vessel manhole (see para. 11.1) the repair of the regenerating vessel is recommended by replacing the bottoms and careful welding as specified. In addition a stress relieving heat treatment can be applied of necessary.

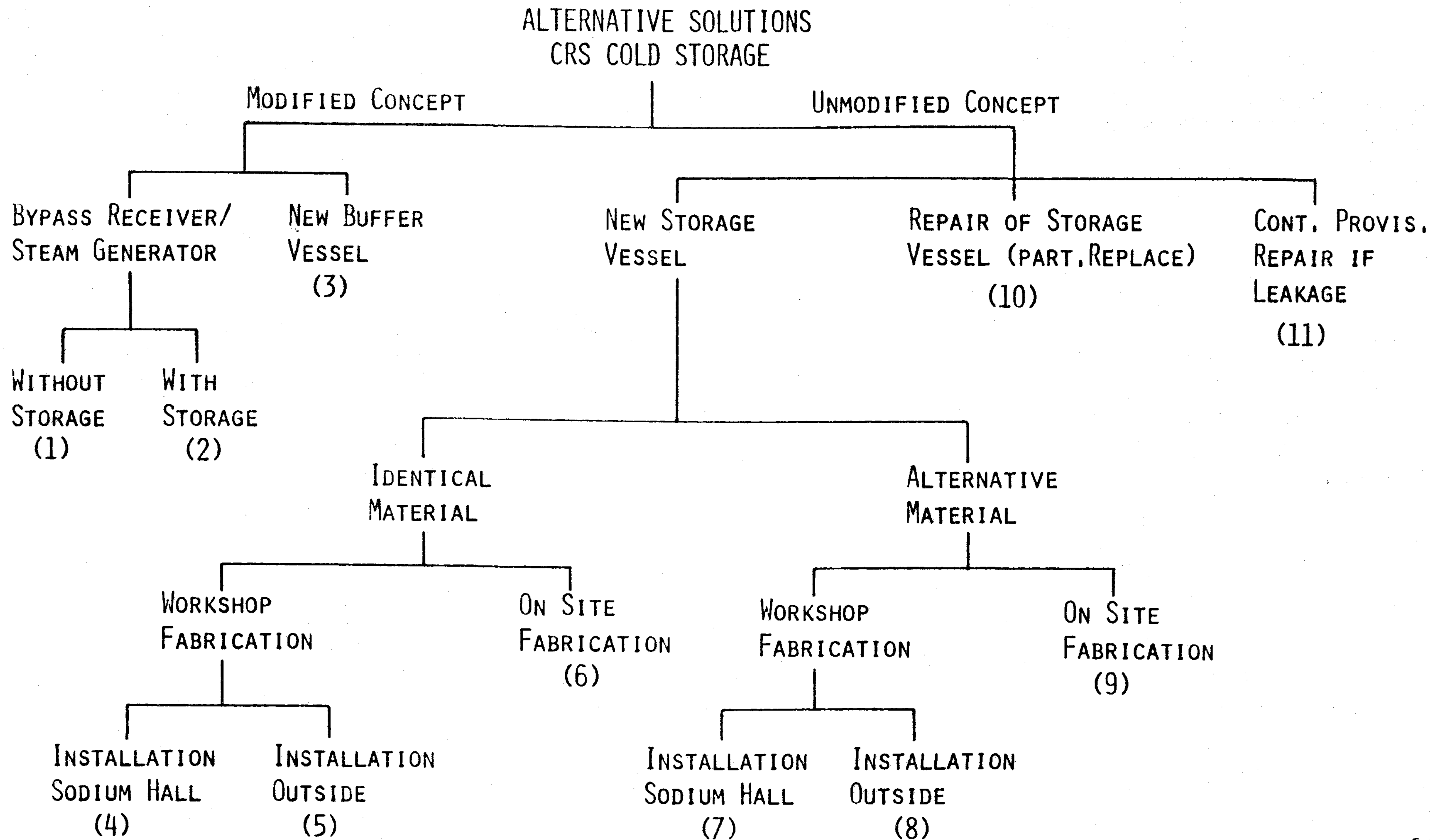
2.1 Repair of the vessel

The detailed repair program is described in chapter I.II.III. The repair activity can be performed in parallel to the work at the cold storage vessel so that not additional delay is to be expected.

SSPS	IEA – SSPS PROJECT CRS	INTERATOM INTERNATIONALE ATOMREAKTORBAU GMBH

Chronology:

28th July 1981	Sodium leakage detected at the lower part of the cold storage tank
Aug. 1981:	
4th-7th	Dismantling of insulation, visual check of the defect, working out of a concept for repair
10th	Interatom documentation concerning checks during fabrication of the vessel. No indication of cracks at that stage. Suspicion, that certain material impurities could have caused the defect.
13th	Ultrasonic tests, showing no further cracks
18th-25th	Repair works, carried out by drilling holes at the end of the crack and covering the whole area with a stud (170 mm diameter) and bottom.
Sept. 1981:	
7th	Sodium leakage at the weld (Position 2 o'clock) between manhole stud and bottom
9th-10th	X-ray and repair welding
14th-15th	Sodium leakage at position 5 o'clock at the manhole stud, repair by welding
18th-19th	Sodium leakage at position 12 o'clock and repair welding
30th	Documentation of Interatom and first explanations about the defects: suspected reasons for the defect at the bottom: pore in the weld initiated crack, propagation due to thermal and bending stresses. Reasons for the defects at the manhole stud: improper welding (high content of chromium in the welds leads to the assumption of a mistake), micro-cracks in the welds from fabrication process (on-site welds), not detectable by X-ray
Oct. 1981 to Dec. 1981	Repair concepts for the manhole-stud (new part of the tube and new bottom) worked out. Recommendations for US-tests at the bottom of the tank and for further works (grinding of the welds). The US test should give a status about the areas surrounding the baffle plates and should be repeated after 1000 and/or 3000 hours of operation
Jan. 1982	
2nd	Repair works at the manhole stud
2nd-9th	US tests at the vessel's bottom: different cracks found
14th-22nd	Elaboration of a repair concept
Feb. 10th - Mar. 24th.	Repair works at the tank's bottom: Separating the areas affected by cracks from the walls (with screwed joints), covering all the areas with tubes and bottoms.



Appendix 2a

12.10.82

SSPS

IEA – SSPS PROJECT CRS

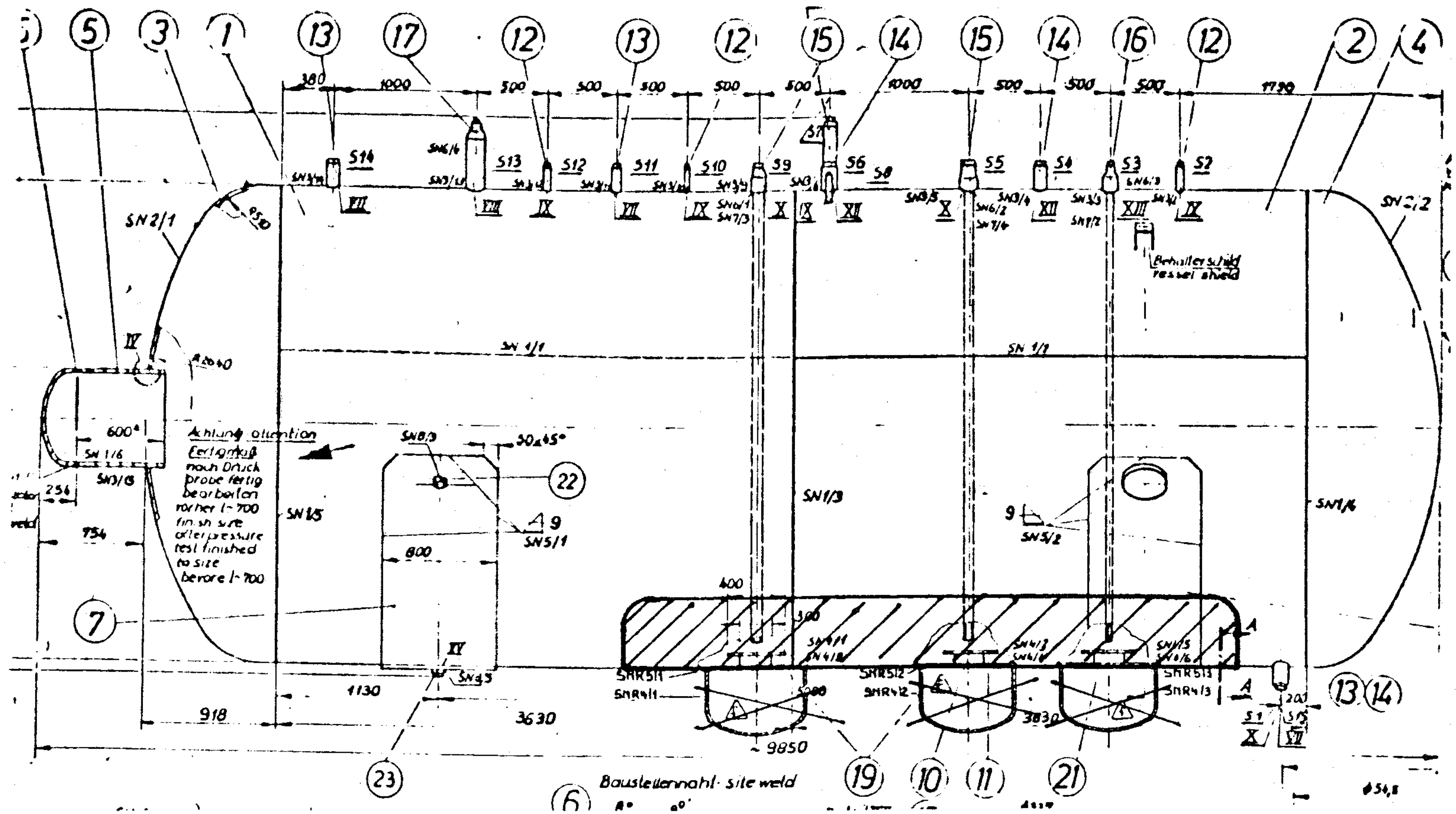
INTERATOM
INTERNATIONALE ATOMREAKTORBAU GMBH

1:211 10-79 2 (SSPS/002/4000)

SUMMARY OF THE EVALUATION OF ALTERNATIVE SOLUTIONS FOR THE NA-COLD STORAGE

NO.	DESCRIPTION OF SOLUTION	TOTAL REQUIRED TIME (MONTHS)	INTER-RUPTION OF OPERATION (MONTHS)	ESTIMATED COSTS (MIO DM)	QUALITY OF SOLUTION	VALUATION OF REPAIR TIME OPERAT. INTERRUPTION	TOTAL EXPECTED COSTS	(1 = GOOD, 3 = BAD) FEASIBILITY OF SOLUTION	SUM
1	CONNECTION RECEIVER/STEAM GENERATOR WITHOUD COLD STORAGE	10	2,5	0,8	2	1	1	2,5 - 3	6,5 - 7
2	CONNECTION RECEIVER/STEAM GENERATOR WITH COLD STORAGE	10 (+ ?)	3	1,0 (+ ?)	2	3	3	2,5 - 3	10,5 - 11
3	NEW BUFFER VESSEL	10	3	0,9	2	2	2,5	1	7,5
4	NEW STORAGE VESSEL (IDENT. MAT.) WORKSHOP FABR., INSIDE SHTS	11	3,5	1,1	1	2	3	1	7
5	NEW STORAGE VESSEL (IDENT. MAT.) WORKSHOP FABR., OUTSIDE SHTS	11	3,5	1,2	1	2	3	1,5	7,5
6	NEW STORAGE VESSEL (IDENT. MAT.) PREFABR. IN WORKSHOP, ASSEMB. ON SITE	11 - 12	6 - 7	1,6	1	3	3	1	8
7	NEW STORAGE VESSEL (ALTERN. MAT.) WORKSHOP FABR., INSIDE SHTS	13	3,5	1,3	1	2,5	3	1	7,5
8	NEW STORAGE VESSEL (ALTERN. MAT.) WORKSHOP FABR., OUTSIDE SHTS	13	3,5	1,3	1	2,5	3	1,5	8
9	NEW STORAGE VESSEL (ALTERN. MAT.) PREFABR. IN WORKSHOP, ASSEMB. ON SITE	13 - 14	7 - 8	1,7	1	3	3	1	8
10	GENERAL REPAIR OF COLD STORAGE VESSEL	4	4	0,85	1	1,5	2	1	5,5
11	PROVISIONAL REPAIR OF COLD STORAGE VESSEL	0,5 X ?	0,5 X ?	?	3	2	1 - 2	2 - 3	8 - 10

Appendix 2b



Repair area at the lower part of the vessel

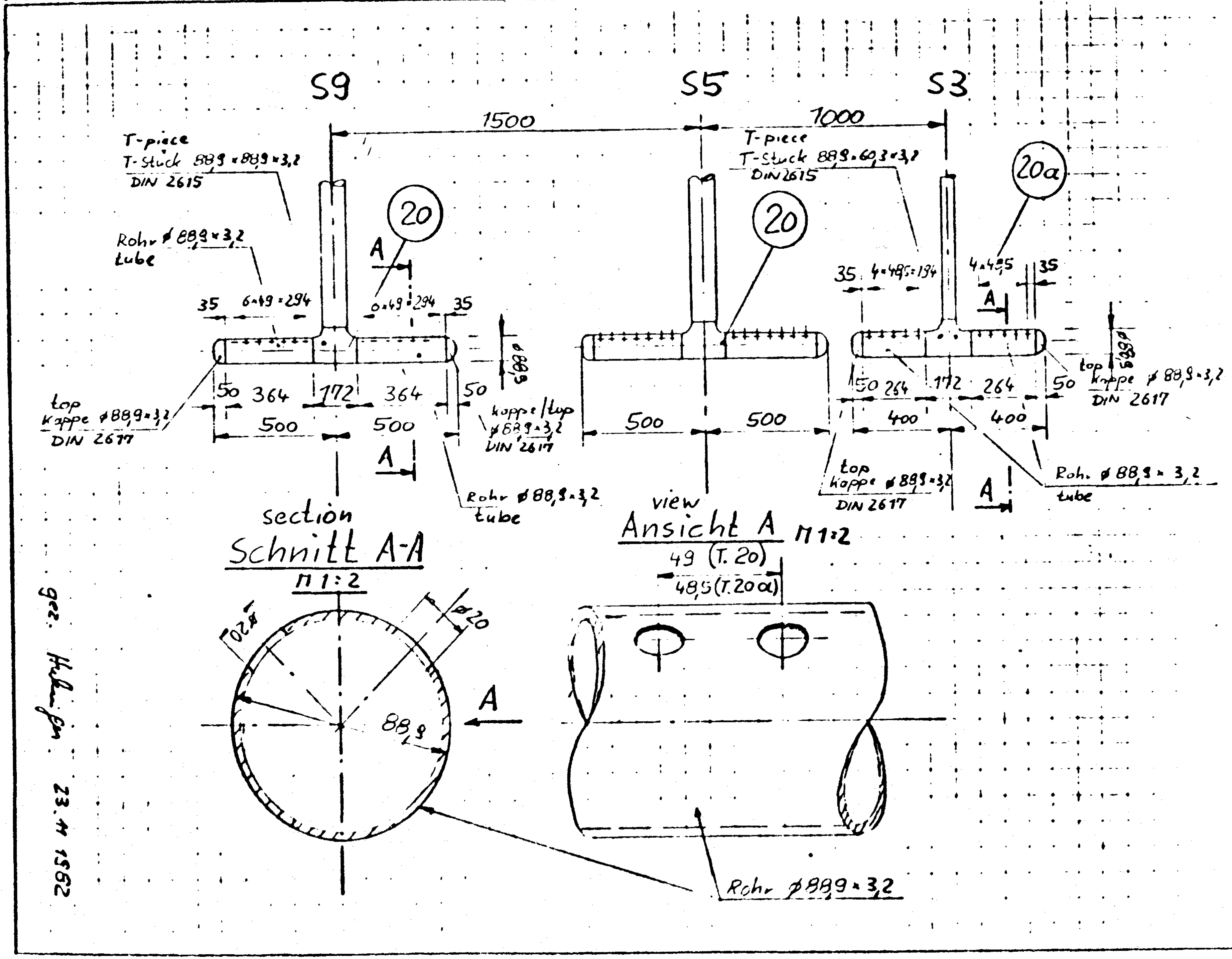
Cold Na-Storage Vessel

Appendix 3

IEA – SSPS PROJECT CRS

INTERATOM
INTERNATIONALE ATOMREAKTORBAU GMBH

EF-34501-L



VOEST-ALPINE AG
Finalbereich Linz
Finished Products Division

CRS- ALMERIA
Kalter Na-Speicher
cold sodium storage vessel

Zeichng Nr
Drwg Nr
5732 17634
8210/1

Appendix 4

CHAPTER I.II

Detailed Technical Descriptions
and Programs

Chapter I.II.I
Repair Program for the
Cold Storage Vessel LK01 BB01

Prepared by:	VOEST ALPINE/INTERATOM
TVS-No.:	129646
Date:	82-11-25
Revision:	0
Approved by:	

Contents

		Performed by
1	Description of Repair	
1.1	Conditions for the Cold Sodium Storage Vessel before Repair	
	- Vessel insulation dismantled in the zone of the Repair Studs 1, 2, 3 and the manhole.	INTERATOM
	- Cover of manhole cut off.	INTERATOM
	- All sodium pipings dismounted and closed.	INTERATOM
	- Vessel lifted and supported by auxiliary vessel support construction, saddle support dismounted.	VAL
	- Vessel moving support locked.	VAL
	- Vessel totally cleaned inside. (INTERATOM-doc. no. 51.02503.1 "Beschreibung der Reinigungsmethode für den kalten Na-Speicher LK 01 in Almeria" vom 1982-10-08 resp. INTERATOM-proposal vom 1982-10-26 "Draining and Cleaning of Sodium Vessel")	INTERATOM
	- Material samples taken out and holes closed (material sample taking acc. to INTERATOM-proposal from 1982-10-26 "Cutting out and protecting of a material sample from the cold sodium storage vessel")	INTERATOM/ TÜV

VAL = VOEST- ALPINE

TÜV = Techn. Überwachungsverein, Köln

		Performed by
	- Testing of the material sample performed as far as possible acc. to INERATOM-doc.-no. 55.05683.3, TVS-no. 401764 from 1982-10-28 "Nachuntersuchungsvorschlag für Topf 2 des Kalten Speichers".	TÜV
1.2	Repair Procedure	
1.2.1	Testing of the inside surface of the vessel and the welds acc. to VA-Process Inspection Plan No. SO2	VAL/INTERATOM/ TÜV
	- MT of the whole surface inside of the vessel - UT of the lingitudinal, circumferential and nozzle welds - VT of the whole surface inside of the vessel	
1.2.2	Substitution of the part of the vessel acc. to VA-drawing No. 57.32.17634/8210 Rev. g and 57.32.17634/8210-SO1	VAL
	- tracing of the vessel part to be burned out, UT of the welding zones - stiffening of the vessel in the middle part (edge of the hole) - burning out of the vessel part and the chord plate - removing of the burned parts - setting of the chord plate by grinding	

Performed by

- caulking out of the concrete support of the saddle for the lug welding
- adapting of the vessel part
- testing during welding acc. to process inspection plan no. SO2
- welding of the vessel part acc. to SP no. SO1
- grinding smooth and ground flush of the welds inside and outside
- welding of the new sodium inlet parts of the backflow pipings acc. to VA-dwg.no. 57.32.1/8210/1 and SP SO4
- Welding of the chord plate acc. to SP SO2 — VAL

1.2.3 Stress relieve heat treatment acc. to WBP SO1 — VAL

- insert of the heaters and applying of the temperature control elements
- completion of the thermal insulation
- unlocking of the vessel moving support
- stress relieve heat treatment of the vessel
- locking of the vessel moving support
- testing of the welds acc. to process insp. plan no. SO2

		Performed by
1.2.4	Exchange of the saddle (see VA-Drawing No. 57.32.17634/8250-1/SO1)	VAL

- installation of the saddle, welding
- testing of the welds acc. to drawing
- painting of the welding zones
- fixing of the saddle to the concrete support by screwing
- sheding of the lug weld zone in the support

1.2.5	Cleaning and Remounting of the Vessel	VAL

- cleaning of the vessel
- drying of the vessel
- completion of the thermal insulation between vessel and saddle
- lowering of the vessel into the supports
- unlocking of the vessel moving support

1.2.6	Mounting of the piping system (Va-drawing in preparation)	VAL

- mounting and welding of the piping system
- testing of the piping system acc. to process inspection plan SO3

1.2.7	Closing of the manhole	VAL

- preparation of the weld edge
- welding of the manhole cover acc. to SP SO3
- testing acc. to process insp. plan SO2 (in preparation)

		Performed by
1.2.8	Leak Test acc. to process inspection plan no. SO2	
1.3	Rest works on vessel and piping - remounting of trace heating - remounting of thermal insulation - reinstallation of electrical cabling	INTERATOM
1.4	Check-Out and start-up - check of trace heating system - evacuating of vessel and adjacent piping - filling of vessel and piping with argon - switch-on of trace heating system	INTERATOM/ Sevillana

2 Testing Plan

2.1 Semifinished Products

- Vessel part: MT of the weld edges
  UT of the welding zone 100 %
  and girder pattern 200 mm in-
  side acc. to UT-Plan no. 20
  and acc. to specification
  WVS 262.
- chord plate: similar to vessel part,
  UT acc. to UT-Plan no. 21
- saddleplates: acc. to specification
- piping parts: acc. to specification and
  SC testing of the weld
  edges

2.2 Inprocess Inspections at VA

- saddle: SC-Testing of the weld seams
  (spot checks).

2.3 Inprocess inspections on the site acc. to
to process inspection plan no. SO2 and
SO3

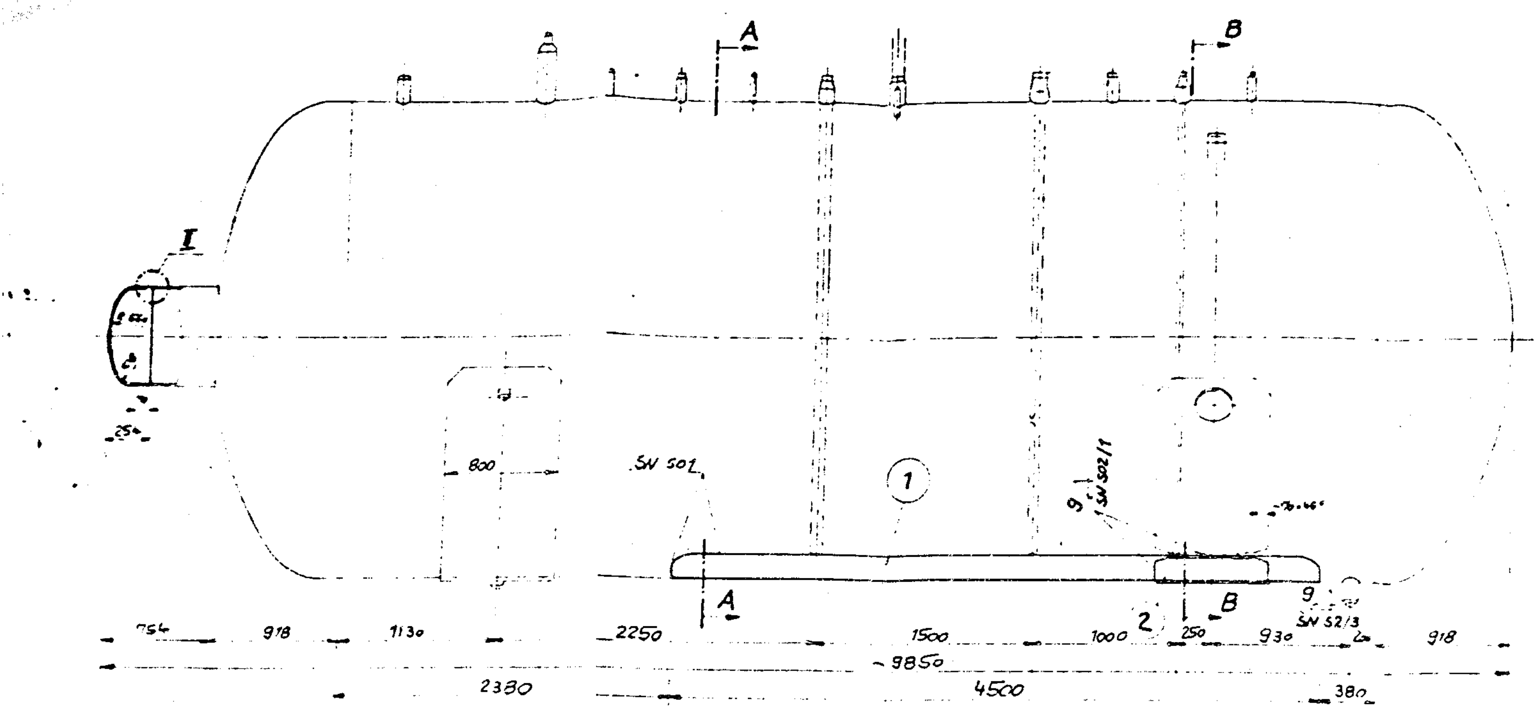
3 Time Schedule

The attached time schedule (see appendix) indicates in detail the process of the repair. The activities with respect to para. 1.2 "Repair procedure" can start immediately after the necessary decision has been made officially.

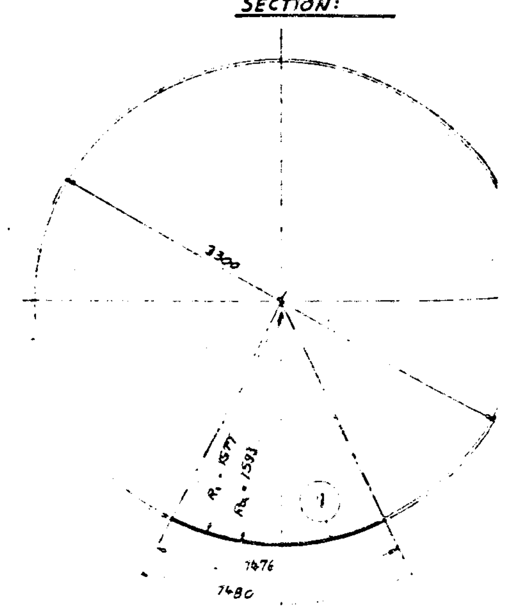
4 Appendix

The following documents and drawings are attached:

- VA-drawing no. 57.32.17634/8210-SO1
- VA-drawing no. 57.32.17634/8250-1/SO1
- Welding plans SO1
  SO2
- Process inspection plans SO1
  SO2
- US-Prüfplan no. 20, 21
- WPB SO1
- Time Schedule
- Calculations



SCHNITT: A:A
SECTION:



Bemerkungen - remarks:

Teil 1 / Pos 1 — wird auf Baustelle eingebaut
assembled on site

SN-Vorbereitung und Rollen durch TLP 3
preparing of welds and bending of shell-pl. at workshop TLP 3

Prüfung der Schweißkanten vor Versand
examination of weld-edges before dispatch

Teil 2 / Pos 2 — wird auf Baustelle eingebaut
assembled on site

SN-Vorbereitung und Rollen durch TLP 3
preparing of welds and bending of shell-pl. at worksh. TLP 3

Zur Zeichnung gehören folgende Unterlagen
the following belongs to this drawing

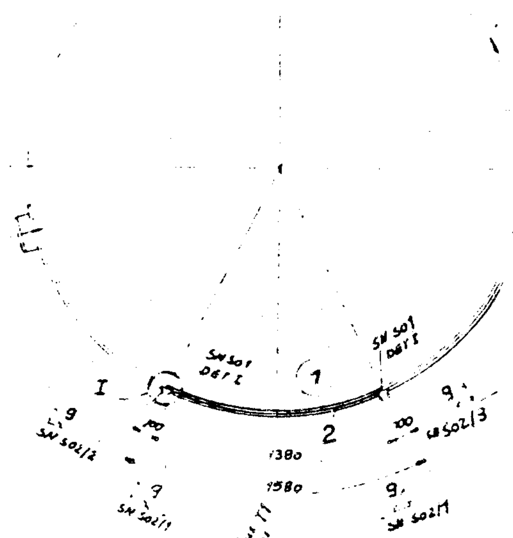
SP 501, SP 502, SP 503

Bauprüfplan 501,502 | PROCESS INSPECTION PLAN 501, 502

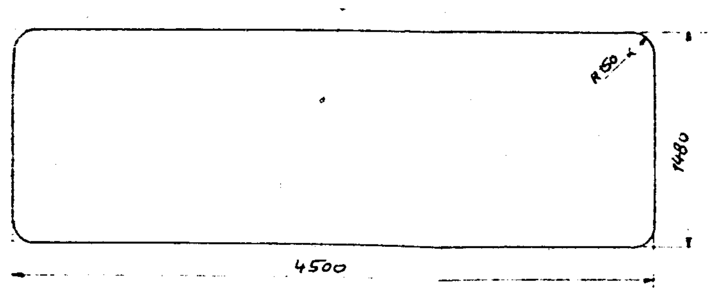
UT-Prüfplan Nr. 20/21 | UT Eximinationsplan No 20/21

Reperaturprogramm kalter Na-Speicher
repair program cold sodium storage vessel

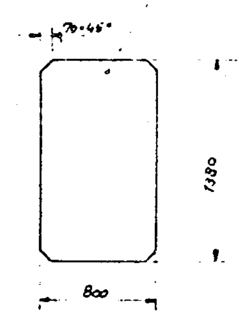
SCHNITT: B:B
SECTION:



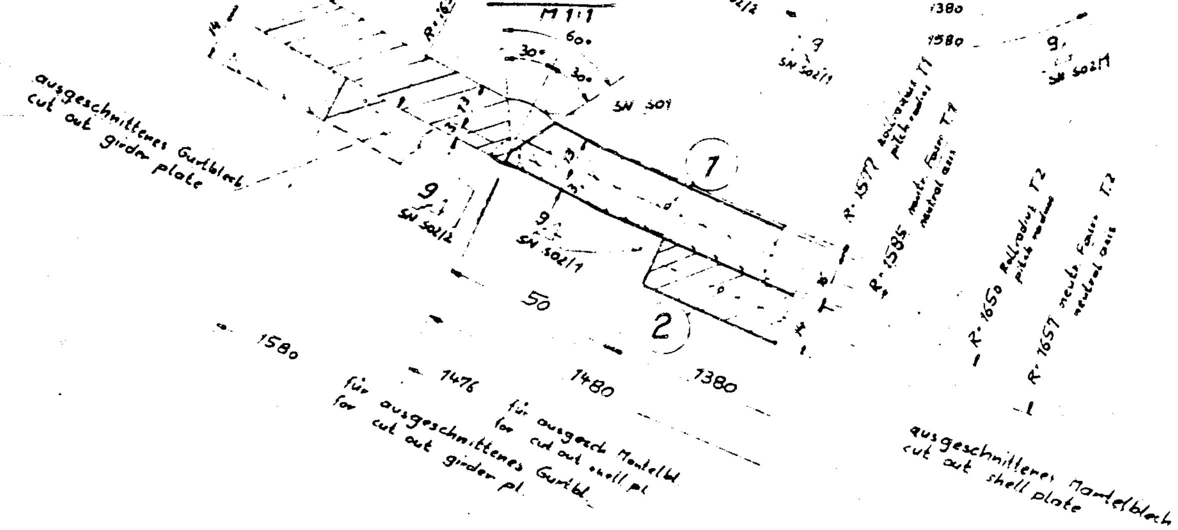
1



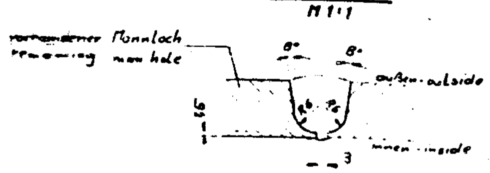
2



DETAIL I
M 1:1

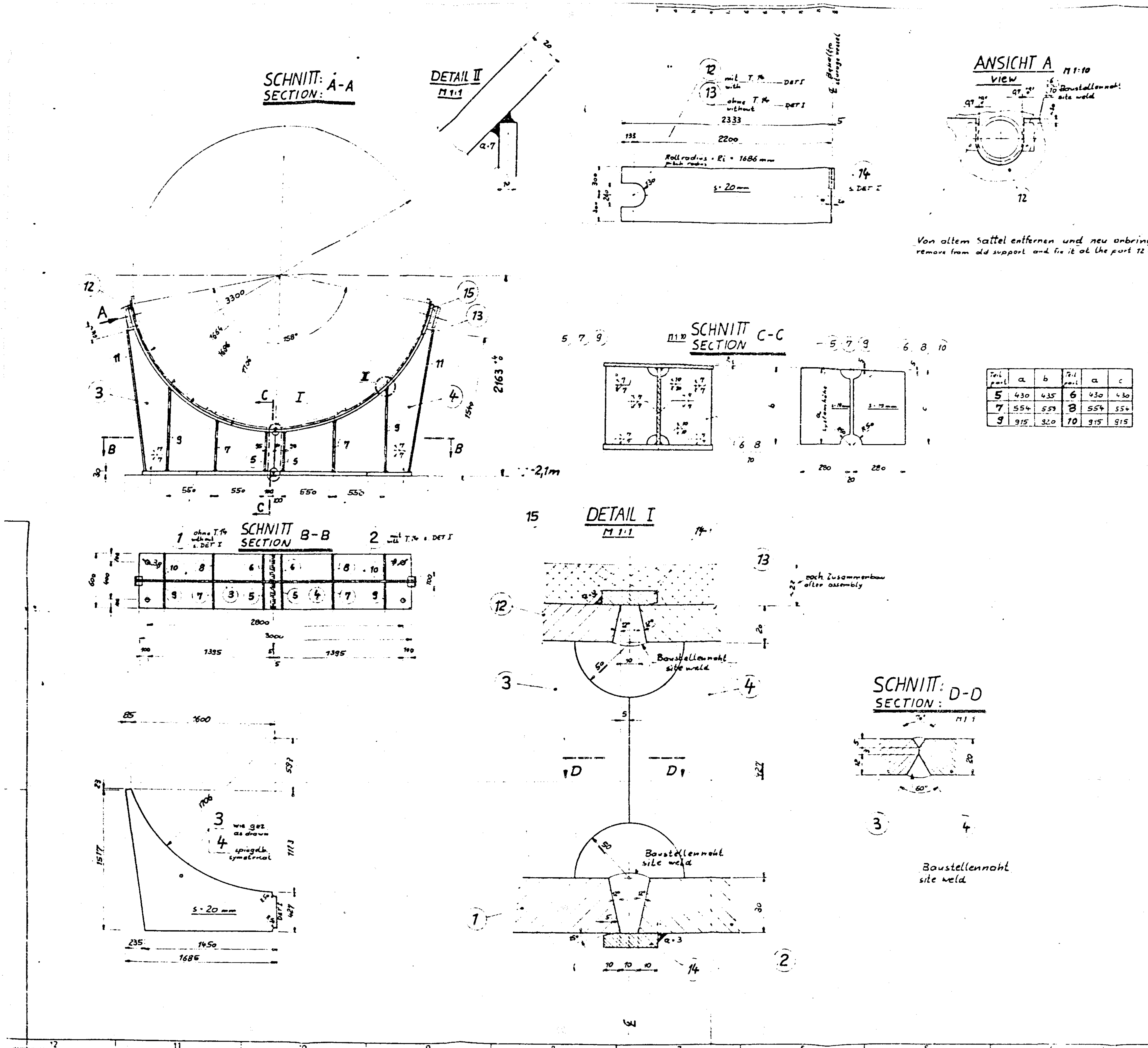


Detail II
M 1:1

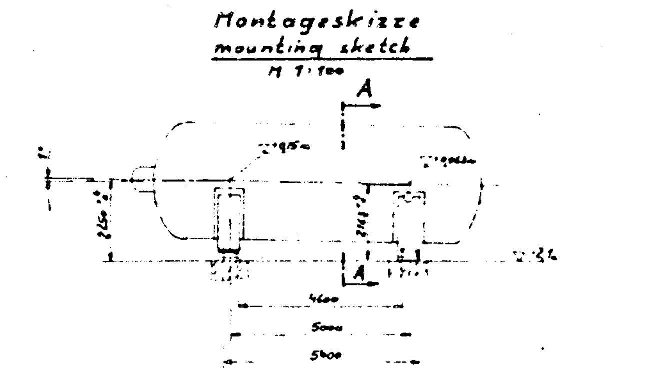


Stück / piece	Benennung / nomenclature	Abmessung / dimension	Teil / part	Material / material	WVS Nr	Anford.-stufe / class-grade
1	Gurtblechstück - piece of chord pl.	14 × 800 × 1380	2	15 Mo 3	262	2
1	Mantelstück - piece of shell	16 × 1480 × 4500	1	15 Mo 3	262	1

Bearbeiter	82-11-11 Hubinger
Geprüft / Checked	82-11-19 Grasser
VOEST-ALPINE AG	Apparate- und Stahlbau / Apparatus and Steel Department
Zeichnungs-Nr. / Drawing No	57.32 17634 / 18210 - 501
Maßstab / Scale	1 : 25, 1 : 1
Bauvorh. / Projekt	CRS - Almeria
Bauherr / Purchaser	Interatom
Benennung / Title	Kalter Na-Speicher - cold sodium storage vessel



Teil part	a	b	Teil part	a	c
5	430	435	6	430	430
7	554	559	8	554	554
9	915	920	10	915	915



Bemerkungen: remarks

Zur Zeichnung gehören folgende Unterlage
the following belongs to this drawing
Reparaturkonzept: repair program

1. Schweißzusatzwerkstoff / filler metal / : Böhler FOX EV 47
2. Schweißnahtausführung nach DIN 8563/3 allg. BK jedoch über 13 AK
   style of SN acc DIN 8563/3 acc. BK, however over 13 AK
3. Prüfung des SN nach DIN 8563/3 · VT, DT(stichproben) MF(stichprob. 10%)
   Abnahme: Hersteller (Interatom)
   testing of SN acc. DIN 8563/3 · VT, DT (spot-checks), MF (spot checks 10%)
   inspection manufaturer (Interatom)
4. Hauptzeichnung / construction draw BL 8210
5. Reinigung / cleaning / sandstrahlen sand blasting
6. Korrosionsschutz – corrosion protection: Athylsilikatzink – Anstrich / coat
   Ausnahme: SN-Bereich der Baustellennähte Anstrich: Schweißprimer
   exception: SN – zone of site welds coat: weldprimer

Stück piece	Benennung nomenclature	Abmessungen dimension	Teil part	Material material	WVS-Nr	Anford. stufe class-grade
2	Isolation – insulation	~25 × 800 × 4750	15	min.-wool		
2	Schweißlasche – mounting lug	⌀30 × 6 × 600	14	H II	270 01	2
1	Gurtblech – girder plate	20 × 600 × 2333	13			
1	Gurtblech – girder plate	20 × 600 × 2333	12			
2	Rippe – rib	10 × 100 × 1540	11			
2	Rippe – rib	10 × 280 × 915	10			
2	Rippe – rib	10 × 280 × 920	9			
2	Rippe – rib	10 × 280 × 554	8			
2	Rippe – rib	10 × 280 × 559	7			
2	Rippe – rib	10 × 280 × 430	6			
2	Rippe – rib	10 × 280 × 435	5			
1	Stegblech – web-plate	20 × 1540 × 1685	4			
1	Stegblech – web plate	20 × 1540 × 1685	3			
1	Grundplatte – base plate	30 × 600 × 1495	2			
1	Grundplatte – base plate	30 × 600 × 1495	1	H II	270 01	2

Bemerkungen / remarks:

7) Sattel in 2 Teilen liefern und auf Baustelle miteinander verschweißen
   dispatch of support in 2 parts and weld on site
8) Baustellenanstrich der fertig geschw. Nähte } Athylsilikatzink
   site-coat of weld seam

VOEST-ALPINE AG
Apparate- und Stahlbau
Apparatus and Steel Department

Bearbeitet / Designed: 82-11-8 Hubinger
Geprüft / Checked: Grosser

Zeichnungs-Nr. / Drawing-No: 57.32 17634/18250-1-S01

Maßstab / Scale: 1:20, 1:10, 1:1, 1:100

Bauwerk / Projekt: CRS - Almeria

Bauherr / Purchaser: Interatom

Benennung / Title: Sattel für kalten Na-Speicher
support for cold sodium storage vessel

Hersteller / manufact.	VOEST-ALPINE AG
Werk Nr / order no	57 32 17634
Zeichnung Nr / drawing no	8210 - S01

PROCESS INSPECTION PLAN Bauprüfplan S01

Prüfplan Nr. / examination pl. no — Revision — Seite 1 von 1

Besteller / customer: INTERATOM

Projekt / project: CRS - ALMERIA
Anlageteil / part: Kalter Na-Speicher / COLD SODIUM STORAGE VESSEL
Auftragnummer des Bestellers / P. order no

Benennung / nomenclature: CRS ALMERIA COLD SODIUM STORAGE VESSEL
Spezifikation des Bestellers / specification no: CRS SOLAR POWER PLANT 2.4.2.4.
Druck / pressure: 80
Temperatur / temperature: 275 °C

Prüfumfang und Nachweiszusammenstellung / Typ of inspection and list of records

	Benennung des Prüfteiles / check part	US-PRÜFUNG UT PLAN Nr. 20 / UT acc to UT plan No 20	Verwechslungprüfung / insp. with ref. to mat. mix up	Prüfung der APZ / control of the mat. cert.	Stempelkontrolle / control of the marking	Maßkontrolle u. Kontr. der Bauaust. / dim. control and in acc. with stowas	OR-Prüfung der Sx. / SC test of the weld flank
1	Behälterblech / vessel plate	H, K2, T1	H	H, K1, T2	H, K1, T2	H, K1, T2	H, K2, T2
2	Gurtblech / chord plate	H	—	H, K1	H, K1	H, K1	—

Erfüllungszeichen
X = erfüllt
O = sinngemäß erfüllt
— = nicht erfüllt

H - Hersteller
K_1 - Interatom
K_2 - IA (Teilnahme vorbehalten) (in own oppinion)
T_1 - TÜV / T_2 - TÜV (Teilnahme vorbehalten) (in own oppinion)

den 19. 11. 1982 Hubinger — Hersteller

den ________ 19 ____ — Besteller

den ________ 19 ____

FACHBEREICH KERNREAKTOREN
Fachgebiet Leistungsreaktoren

Hersteller / manufact: VOEST-ALPINE AG	PROCESS INSPECTION PLAN **Bauprüfplan** S02		Besteller / customer: INTERATOM	Projekt / project: CRS - ALMERIA
Werk Nr / order-no: 57.32. 17634				Anlageteil / part: Kalter Na-Speich. / COLD SODIUM STORAGE VE...
Zeichnung Nr / drawing no: 8210 - S01	Prüfplan Nr. / examination pl no:	Revision:	Seite 1 von 2	Auftragnummer des Bestellers / P. order no:
Benennung / nomenclature: CRS - ALMERIA, COLD SODIUM STORAGE VESSEL				
Spezifikation des Bestellers / specification no: CRS SOLAR POWER PLANT 2.4.2.4	Druck / pressure: 8,0	Temperatur / temperature: 275°C		

Prüfumfang und Nachweiszusammenstellung / Typ of inspection and list of records

Benennung des Prüfteiles / check part		Visuelle Kontrolle / visuell testing	OR-Prüfung der ges. Behälteroberfl. innen / SC-testing of the vessel surf. inside	US-Prüfung UT-Schweißnaht / US-testing UT-weld	US-Prüfung des SK-Bereichs / UT-welding zones	OR Prüfung der SK / SC-test of weld edges	OR-Prüfung der ausgeschliffenen Wurzel / SC-test of root	OR-Prüfung der fertigen Naht / SC test of weld		Maßkontr. stichprobenweise / dim. testing spot checks
Kalter Na-Speicher ges. / cold sodium storage vessel total	Zeichn. Nr. 5732 17634 8210	H, K_1, T_2	H, K_2, T_1							
SN 1/3 / weld no 1/3	"			H, K_2, T_1						
SN 1/4 / weld no 1/4	"			H, K_2, T_1						
SN 1/5 / weld no 1,5	"			H, K_2, T_1						
SN 1/1 / weld no 1,1	"			H, K_2, T_1						
SN 1/2 / weld no 1/2	"			H, K_2, T_1						
SN 3/15 / weld no 3/15	"			H, K_2, T_1						
SN S01 / weld no S01	Zeichng Nr. 5732 17634 8210-S01	H, K_1, T_2		H, K_1, T_1	H, K_2, T_1	H, K_2, T_1	H, K_2, T_1	H, K_1, T_1		H, K_1, T_2
SN S02/1 / weld no S02/1	"	H, K_1, T_2			H, K_2, T_1	H, K_2, T_1		H, K_1, T_2		H, K_1, T_2
SN S02/2 / weld no S02/2	"	H, K_1, T_2			H, K_2, T_1	H, K_2, T_1		H, K_1, T_2		H, K_1, T_2

Erfüllungszeichen
x = erfüllt
O = sinngemäß erfüllt
— = nicht erfüllt

H - Hersteller
K_1 - Interatom
K_2 - IA (Teilnahme vorbehalten) (in own oppinion)
T_1 - TÜV / T_2 - TÜV (Teiln. vorbeh.) (in own oppinion)

den 18. 11. 19 82 — Hubinger — Hersteller

den ______ 19 ____ — Besteller

den ______ 19 ____

AEG/S 31 3810 1 30/8171

FACHBEREICH KERNREAKTOREN
Fachgebiet Leistungsreaktoren

Hersteller / manufact: VOEST-ALPINE AG	PROCESS INSPECTION PLAN Bauprüfplan S02	Besteller / customer: INTERATOM	Projekt / project: CRS - ALMERIA
Werk Nr / order no: 57.32. 17634			Anlagenteil / part: Kalter Na-Sp. / COLD SODIUM STORAGE
Zeichnung Nr / drawing no: 8210 - S01	Prüfplan Nr. / examination pl. no — Revision — Seite 2 von 2		Auftragsnummer des Bestellers / P. order no

Teilungs-benennung / nomenclature	CRS - ALMERIA COLD SODIUM STORAGE VESSEL
Spezifikation des Bestellers / specification no	CRS SOLAR POWER PLANT 2.4.2.4
Druck / pressure	80
Temperatur / temperature	275°C

Prüfumfang und Nachweiszusammenstellung / Typ of inspection and list of records

Benennung des Prüfteiles / check part		Visuelle Kontrolle / visuell testing	OR. Prüfung der ges. Behälteroberfl. innen / SC testing of the vessel surface inside	US-Prüfung UT-Schweißnaht / US-testing UT-weld	US-Prüfung des SK Bereiches / UT-welding zones	OR Prüfung der SK / SC-test of weld edges	OR-Prüfung der ausgeschliffenen Wurzel / SC-test of root	OR-Prüfung der fertigen Naht / SC test of weld		Hebk. Stichproben / DT spot checks	Dichtheitsprüfung / fear test	Reinheitskontrolle / purifying control	Prüfen der mitlaufenden Arbeitsproben / qualification test
SN S02/3 weld no S02/3	Zeichn. Nr. 5732 17634 8210 - S01	H, K1, T2			H, K1, T1	H, K2, T1		H, K1, T2		H, K1, T2			
SN 4 1/1 weld 4 1/1	5732 17634 8210	H, K1, T2		H, K2, T1	H, K2, T1	H, K2, T1		H, K1, T1		H, K1, T2			
Behälter ges. storage vessel											H, K2, T1		
Behälter ges. storage vessel.												H, K1, T2	
SN S01 weld no S01													H, K1, T1

Erfüllungszeichen
X = erfüllt
O = sinngemäß erfüllt
— = nicht erfüllt

H · Hersteller
K1 · Interatom
K2 · IA (Teilnahme vorbehalten) (in own oppinion)
T1 · TÜV, T2 · TÜV (Teiln. vorbehalten) (in own oppinion)

den 18. 11. 1982 Hubinger — Hersteller
den ____ 19__ — Besteller
den ____ 19__ — TÜV

Work seq. no. / Arb.-Schritt	Welding process / Schweißverfahren	WELDING SEQUENCE / Schweißfolge	Weld position / Schweißposition	No of layers / Lagenzahl	Electrode Ø / Elektrode Ø (mm)	Wire Ø / Draht Ø (mm)	Band size / Bandgröße (mm)	WELD FILLER METAL / Schweißzusatzwerkstoffe: Manuf.[n] designat. / Hersteller Bezeich.; DIN designation / Bezeichnung; AWS designation / Bezeichnung	Acceptance to / Abnahme nach	No ASME F	No ASME A	FLUX OR SHIELDED BY / Schweißhilfsstoffe: Manufacturer / Hersteller; Flux or inert gas / Pulver oder Schutzgas; Flow rate / Bezeichn. l/min	Acceptance to / Abnahme nach	Gas backing / Spülgas; Flow rate L/min	Acceptance to / Abnahme nach	DRYING / Nachtrocknung: Electrodes or flux / Elektr. °C	h	Current / Stromart	Polarity / Polung	Amperage / Stromstärke [A]	Voltage / Spannung [V]	Travel speed / Schweißgeschwindigkeit cm/min	Oscillation width / Pendelbreite mm	Cycle / Frequenz 1/min	Hot wire / Heißdraht	Feeding / Zuführung	Wire speed / Drahtgeschw. m/min	Preheat temp / Vorwärmtemp. °C	Interpass temp / Zwischenlagentemp. °C max	REMARKS / Bemerkung
3	E	Heften - tack welding	ü	/	3,25	/	/	Bö Fox DMo kb								300-380	2	–	+	110-140	22-28	—	—	—	—	—	—	150	300	
4	E	Wurzel - Füll- u. Decklagen innen / root, filler and cover passes inside	w	/	3,25	/	/	-"-								-"-	"	=	+	110-140	-"-	—	—	—	—	—	—	"	"	falls erforderlich / if necessary / wechselseitig schw. / mutual weld
					4,0	/	/	-"-								-"-	"	=	+	140-180	-"-	—	—	—	—	—	—	"	"	
7	E	Füll- u. Decklagen / filler and cover passes	ü	/	3,25	/	/	-"-								-"-	"	=	+	110-160	-"-	—	—	—	—	—	—	"	"	-"-
					4,0	/	/	-"-								-"-	"	=	+	140-180	-"-	—	—	—	—	—	—	"	"	-"-

WELDEXAMINATION
Schweißnahtprüfung (NO SUBJECT OF APPROVAL) (nicht Gegenstand der Genehmigung)

INTERNAL WORKING NOTES / Interne Arbeitsvermerke: Work step	MT	PT	VT	US	RX	RG	RA	DT	SA	EXAM.[N] BY / Prüfung durch: T	K	H	REMARKS / Bemerkung: EXAMINATION - OPERATION / Prüfung - Arbeitsgang	TO SPEC. OR CODE / n. Spez. od. Vorschr.
1				X						T_1	K_2	H	SN - BEREICH / SN - ZONE	CRS 2.4 Z.4
2	X									T_1	K_2	H	SN - KANTEN / weld edges	RVS-CRS-10/11
6	X									T_1	K_2	H	ausgeschliffene Wurzel / grind out root	
9	X											H	fertige Naht / finished weld	
10				X								H	-"-	
12			X					X		T_1	K_1	H	nach dem Glühen / after s.r.h.t.	
13	X									T_1	K_2	H	nach dem Glühen / after s.r.h.t.	
14				X						T_1	K_2	H	-"-	

ROOT + SURFACE PREPARATION — Wurzel + Oberflächenbehandlung

5	ROOT PREPARATION / Wurzelausarbeitung	~~NONE / Ohne~~	~~GOUGING / Fugen~~	GRINDING / Schleifen
	TO SPEC.[N] / n. Spezifikation			
	NOTES / Bemerkung			
8	SURFACE PREPARATION / Oberflächenbehandlung	~~NONE / Ohne~~		GRINDING FLUSH / ...
	TO SPEC.[N] / n. Spezifikation			
	NOTES / Bemerkung			

HEATTREATMENT — Wärmebehandlung

	TYPE OF HEATTREATMENT / Art der Wärmebehandlung	WBP Nr.	SPECIFIKATION - NOTES / Spezifikation - Bemerkungen
17	Spannungsarm glühen / stress relieve heat treatment	S01	RVS CRS - 05

ADD.[L] FABRICATIONREMARKS — Sonstige Fertigungsanweisungen

APPROVAL — Genehmigung

Rev.	INSPECTION AUTHORITY / Überwachungsgesellschaft	PURCHASER / Kunde
0		
1		
2		
3		
4		

Rev.		APPROVED BY MANUFACTURER / Geprüft durch Hersteller			PREPARED / erstellt	TYPE OF REVISION / Art der Änderung
		TLP 42	TFZ 15	TLS-11	TLS 11	
0	Name	[signature]		Strand	Halbinger	
	Datum	31-M-19				
1	Name / Datum					
2	Name / Datum					
3	Name / Datum					
4	Name / Datum					

MAT.[L] BASE MAT. / Werkstoff-Paarung	NOTATION N-Bez.	DIN	ASTM	ASME	P-NO
		15 Mo 3			
		15 Mo 3			

SN-Type:

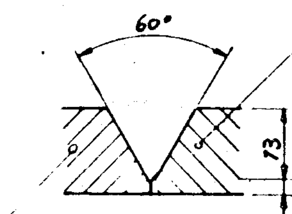
NOTATION / Bezeichnung	EFFICIENCY / SN Wertigkeit	EVALUATION / Bewertung n. DIN 8563	PROCEDURE QUAL.[N] / Verfahrensprüfung	WELDER QUAL.[N] / Schweißerprüfung	WORK SPEC. / Arbeits-Spez.
	1,0	BS	VMo 22/82	E-DIN 8560 BI q	

EDGE PREPARATION BY / Kantenvorarbeitung durch: hobeln / schleifen — plane / grind

INFORMATION FOR EACH SN / Informationen je SN

Dwg. item / Zeichn. Teil Nr.	SN Nr.	A Nr.	TRAN A	SPK Nr.
	S01	AM01		

SN-DETAIL:



Ausgewechseltes Blech
vessel plate for exchange

Bestehender Behälter
old cold sodium storage vessel

WELDPLAN (SP) NO. / SCHWEISSPLAN (SP) NR.:	S01
SH. / Blatt	ERECT.[N] / Montage
SPEC NO / K-Spez. Nr	
DOCUM NO / K-Dok. Nr	
PURCHASER / Kunde	Interatom
PROJEKT / Projekt	CRS-Almeria
PROJ. COMPONENT / Komponente	kalter Na - Speicher / cold sodium storage vessel
SUBJECT / Bauteil	
PURCH ORDER NO / K-Auftrags Nr	
CONTRACT NO. / H-Auftrags Nr.:	57 32 17634
DRAWING NO / H-Zeichngs Nr	8210 - S01
WELD PATTERN DWG NO. / Schweißfolgezeichn. Nr	

FABRICATION INSPEC.[N] / BAUÜBERWACHUNG	
FINAL EXAM.[N] / ENDABNAHME	H, K, TÜV

VOEST-ALPINE AG
STAHL- UND APPARATEBAU LINZ

MT/EM MAGNETIC PARTICLE EXAM.[N] / Magnetpulverprüfung — PT/ET DYE PENETRANT EXAM.[N] / Farbeindringprüfung — VT VISUAL EXAM.[N] / visuelle Kontrolle — US/UE ULTRASONIC EXAM.[N] / Ultraschallprüfung — RX/RÖ X RAY EXAM.[N] / Röntgenaufnahme — RG GAMMA RAY EXAM.[N] / Gammaaufnahme — RA ACCELERATOR EXAM.[N] / Beschleuniger Aufn. — DT HARDNESS TEST — SA / AI TEST COUPON PLATES / Arbeitsproben — VI PROCEDURE QUALIFICATION / Verfahrensprüfung — TFI FABRICATION TEST SEQUENCE / Prüfungs- u. Prüffolge Plan — SN WELD SEAM / Schweißnaht — LN LONG.[L] SEAM / Längsnaht — RN CIRC.[L] SEAM / Rundnaht — R REPAIR / Reparatur — WBP HEATTREATMENT SEQUENCE / Wärmebehandlungsplan — H MANUFACTURER / Hersteller — K PURCHASER / Kunde — T INSPECTION AUTHORITY / Überwachungsgesellschaft

WELDING / Schweißen — WELD FILLER METAL / Schweißzusatzwerkstoffe — FLUX OR SHIELDED BY / Schweißhilfsstoffe — DRYING / Nachtrocknung — WELDPARAMETERS / Schweißparameter

WORK SEQUENCE Arbeitsfolge	WELDING PROCESS Schweißverfahren	WELDING SEQUENCE Schweißfolge	WELD POSITION Schweißposition	NO OF LAYERS	ELECTRODE Ø mm	MANUF. DESIGNAT. Hersteller Bezeichnung / DIN / AWS	ACCEPTANCE TO	ASME F NO	ASME A NO	MANUFACTURER FLUX OR INERT GAS	ACCEPTANCE TO	GAS BACKING Spülgas FLOW RATE L/min	ACCEPTANCE TO	ELECTRODE OR FLUX °C	h	CURRENT	POLARITY	AMPERAGE [A]	VOLTAGE [V]	EXTENSION	OSCILLATION	HOT WIRE	WIRE SPEED m/min	PREHEAT TEMP °C	INTERPASS TEMP °C max
3	E	Heften - tack welding	$\frac{u\,q}{s}$	1	3,25 / 4	Böhler Fox DIto - kb								300-380	2	=	+	110-140 / 140-180	22÷28					150	300
4	E	Fertigschw - finish welding	$\frac{u\,q}{s}$	—	3,25 / 4	—"—								300-380	2	=	+	110-140 / 140-180	22÷28					150	300

INTERNAL WORKING NOTES: / Interne Arbeitsvermerke:
WELDEXAMINATION / Schweißnahtprüfung (NO SUBJECT OF APPROVAL) (nicht Gegenstand der Genehmigung)

	MT	PT	VT	US	RX	RG	RA	DT		EXAM BY T	K	H	REMARKS / EXAMINATION - OPERATION	TO SPEC OR CODE
1				X						T	K1	H	SN-Bereich des Beh. / SN-zone of storage vessel	CRS 24.2.4
2	X									T	K1	H	SN-Bereich des Behälters / SN-zone of storage vessel	RVS-CRS-10.11
6			X					X		T	K1	H	fertige Naht nach glühen / finished weld after s.r.ht	
7	X									T	K1	H	fertige Naht / finished weld -"-	

SN-Type:
NOTATION / Bezeichnung
EDGE PREPARATION BY / Kantenvorbereitung durch:

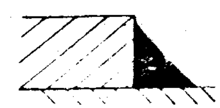
MAT. PAIRING Werkstoff-Paarung	NOTATION N-Bez.	DIN	ASTM	ASME
		15 Mo 3		
		15 Mo 3		

EFFICIENCY SN Wertigkeit	EVALUATION Bewertung n.	DIN BBAB	PROCEDURE QUAL. Verfahrensprüfung	WELDER QUAL. Schweißerprüfung
	AK			DIN 8560 B I g

INFORMATION FOR EACH SN / Informationen je SN

Dwg Item	SN Nr	A Nr	SPAN A	SPK Nr
1				
2	S02			
3	S02			
4	S02			

SN-DETAIL:



ROOT + SURFACE PREPARATION / Wurzel + Oberflächenbehandlung

ROOT PREPARATION / Wurzelausarbeitung — NONE Ohne — GOUGING Fugen — GRINDING Schleifen
TO SPEC. n Spezifikation
NOTES Bemerkung
SURFACE PREPARATION / Oberflächenbehandlung — NONE Ohne — WELDING [illegible] — GRINDING [illegible]
TO SPEC. n Spezifikation
NOTES Bemerkung

HEATTREATMENT / Wärmebehandlung

TYPE OF HEATTREATMENT Art der Wärmebehandlung	WBP Nr.	SPECIFICATION - NOTES Spezifikation - Bemerkungen
5 Spannungsarm glühen / stress relieve heat treatm	S01	CRS -05

ADD. TABRICATIONREMARKS — Sonstige Fertigungsanweisungen

APPROVAL / Genehmigung

Rev	INSPECTION AUTHORITY Überwachungsgesellschaft	PURCHASER Kunde
0		
1		
2		
3		
4		

Rev		APPROVED BY MANUFACTURER Geprüft durch Hersteller			PREPARED erstellt
		TLP 42	TF 2 15	TLS-11	TLS-11
0	Name / Datum	[signature] 82-11-19		[signature]	[signature]
1	Name / Datum				
2	Name / Datum				
3	Name / Datum				
4	Name / Datum				

TYPE OF REVISION / Art der Änderung:

WELDPLAN (SP) NO / SCHWEISSPLAN (SP) NR.: S02

SPEC NO / K-Spez Nr
DOCUM NO / K-Dok Nr
PURCHASER / Kunde: Interatom
PROJEKT / Projekt: CRS - Al[illegible]
PROJ COMPONENT / Komponente: kalter Na-Speicher / cold sodium storage vessel
SUBJECT / Bauteil
PURCH ORDER NO / K-Auftrags Nr
CONTRACT NO / H-Auftrags Nr.: 57 32 17634-
DRAWING NO / H-Zeichnungs Nr: B210 - S01

FABRICATION INSPEC. / BAUÜBERWACHUNG
FINAL EXAM. / ENDABNAHME: H.K. TÜV

MT/ZM MAGNETIC PARTICLE EXAM. / Magnetpulverprüfung — PT/ZF DYE PENETRANT EXAM. / Farbeindringprüfung — VT VISUAL EXAM. / Visuelle Kontrolle — US ULTRASONIC EXAM. — RX X RAY EXAM. / Röntgen Aufnahme — RG GAMMA RAY EXAM. / Gamma Aufnahme — RA ACCELERATOR EXAM. — DT LEAKAGE TEST
AI TEST COUPON PLATES / Arbeitsprobe — VI PROCEDURE QUALIFICATION / Verfahrensprüfung — FM FABRICATION SEQUENCE / Prüfungs- u. Fertigungs-Plan — BMJ WELD REPAIRS
SNI WELD SEAM / Schweißnaht — LNI LONG. SEAM / Längsnaht — RNI CIRC. SEAM / Rundnaht — RI REPAIR
WBP HEAT TREATMENT SEQUENCE / Wärmebehandlungsplan — HI MANUFACTURER / Hersteller — KI PURCHASER / Kunde — TI INSPECTION AUTHORITY

VÖEST-ALPINE AG

VOEST-ALPINE AG
Finalbereich Linz
Finished Products Division

UT - Prüfplan Nr. 20
UT Examinationplan No.

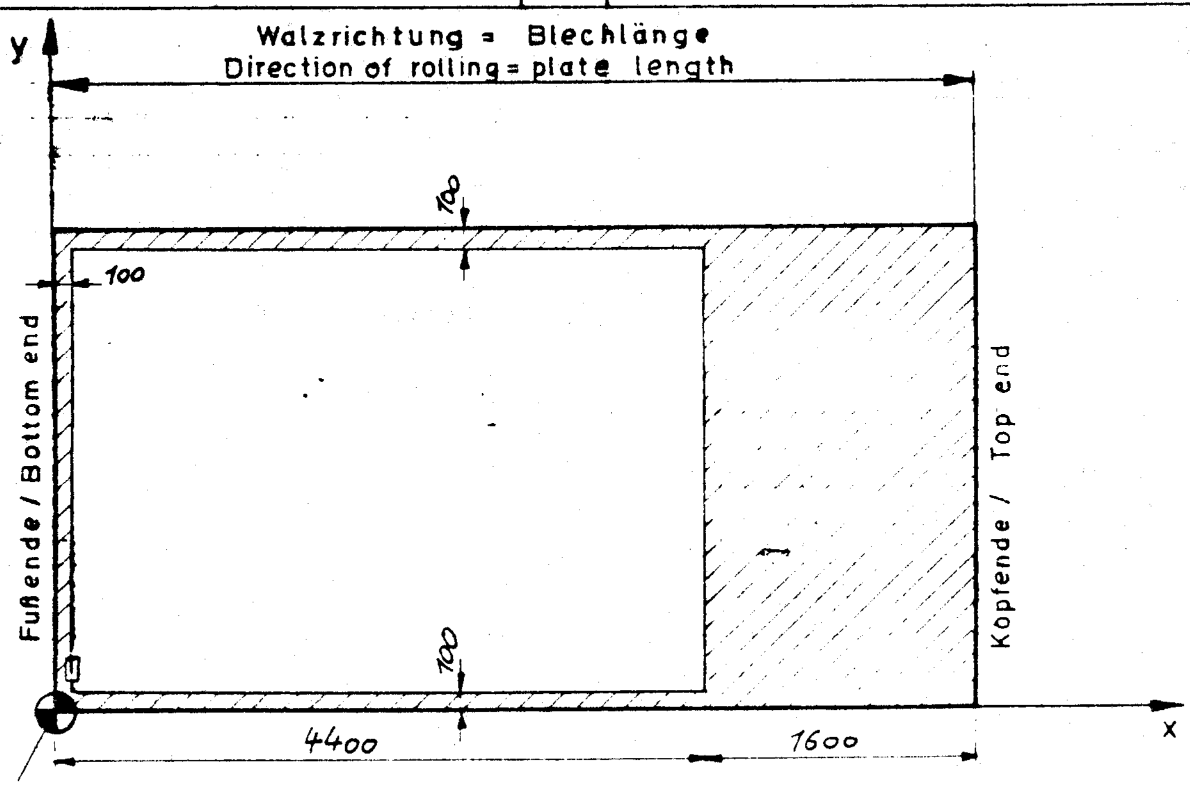
Auftrags-Nr. / Order-No.: 57 32 17634

Seite/Page 1 von/of 1

Pos.	Blechabmessung / Plate dimension			Material	Oberflächenzustand / Surface condition
	Länge: Length	Breite: Breadth	Dicke: Thickness	15 Mo 3	
1	6000	1500	16	1.5415	

Verwendungszweck / Applicability

Stück Piece	Benennung / Nomenclature	Stück Piece	Benennung / Nomenclature
1	Mantelstück / piece of shell		
1	Ronde / round		
1	VP		
1	AP		



Bezugspunkt für Fehlerangaben - gekennzeichnet durch die Blechmarkierung.
Reference point for fault indication - designated by plate marking.

Prüfvorschrift: SEL 072 - 77 Kl. 3
Testing instruction:

☐ Rasterprüfung 200mm (Volumsbereich) / Grid-pattern exam. 200mm (Volume region)

▨ 100%-ige Volumsprüfung 1) / 100% Volume exam. (Schweißkantenbereich / Weld edge region)

1) Bei Anzeigen größer der Registriergrenze für Schweißkantenbereiche KSR 6mm sind die Schweißkantenbereiche anzureißen. Die Beurteilung ist dann wie spezifiziert nach Rasterprüfung und Schweißkantenprüfung vorzunehmen. / In case of indications larger then recording limit KSR 6 mm for welding edges the welding edge zones shall be traced. The evaluation shall be performed after the specified grid line testing and welding edge testing.

Abteilung / Department	Erstellt/Prepared: Hubinger	Tel.: 3669	Dat.: 82-11-16
TLS 11	Geprüft/Checked: Strasser	Tel.: 9386	Dat.: 82-11-16

Art der Änderung / Item | Datum/Date | Erstellt/Prep. | Rev. 1 2 3 4

Genehmigt: Approved:

Verteiler: Copies:

EF-34501-L

VOEST-ALPINE AG
Finalbereich Linz
Finished Products Division

UT - Prüfplan Nr.: 21
UT - Examinationplan No.: 21

Auftrags-Nr/Order-No. 5732 17634

Seite/Page 1 von/of 1

Pos	Blechabmessung / Platedimension			Material	Oberflächenzustand / Surface condition
	Länge / Length	Breite / Breadth	Dicke / Thickness	15Mo3	
1	1700	800	14	1.5415	

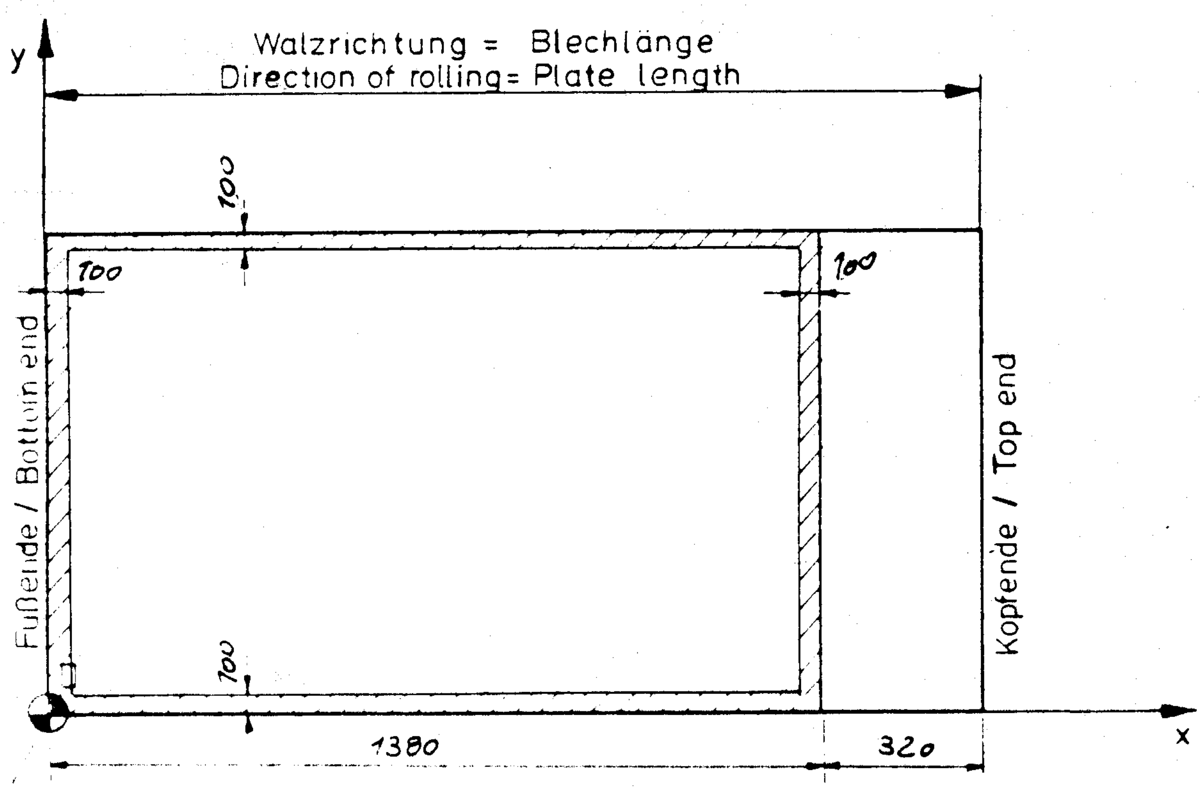
Verwendungszweck / Applicability

Stück / Piece	Benennung / Nomenclature	Stück / Piece	Benennung / Nomenclature
1	Gurtblech / chordplate		

Art der Änderung / Item | Datum/Date | Erstellt/Prep | Rev. 1 2 3 4

Genehmigt: / Approved:

Verteiler: / Copies:



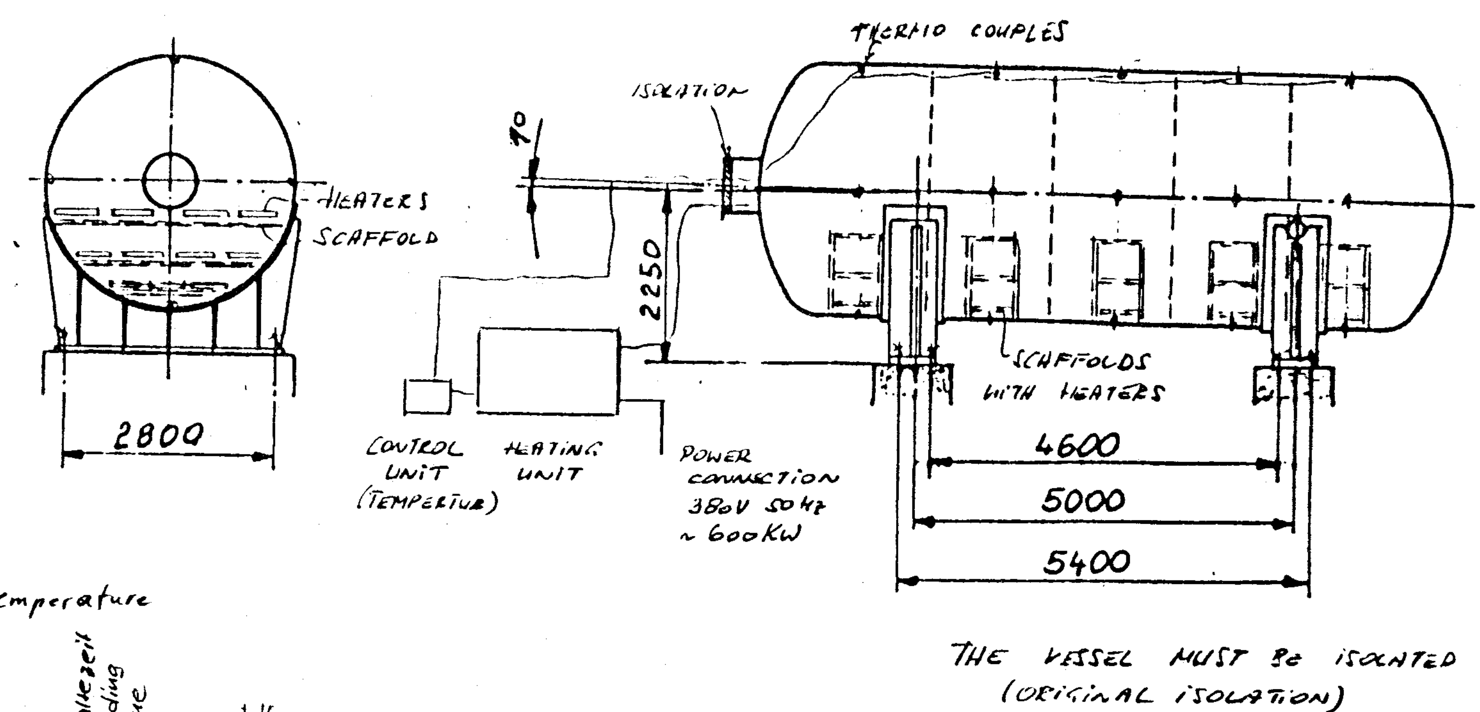
Bezugspunkt für Fehlerangaben - gekennzeichnet durch die Blechmarkierung
Reference point for fault indication - designated by plate marking

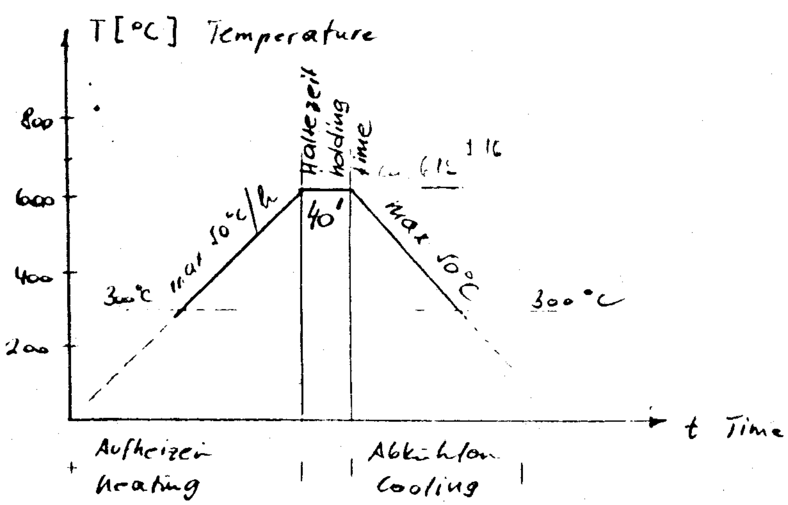
Prüfvorschrift: SEL 072 - 77 kL.3
Testing instruction:

Rasterprüfung 200 mm (Volumsbereich) / Grid-pattern exam. 200 mm (Volume region)	100%ige Volumsprüfung / 100% Volume exam. (Schweißkantenbereich / Weld edge region)

Abteilung / Department	Erstellt/Prepared: Kubinger	Tel.: 3669	Dat.: 82-11-16
TLS 11	Geprüft/Checked: Skamu	Tel.: 9386	Dat.: 82-11-16

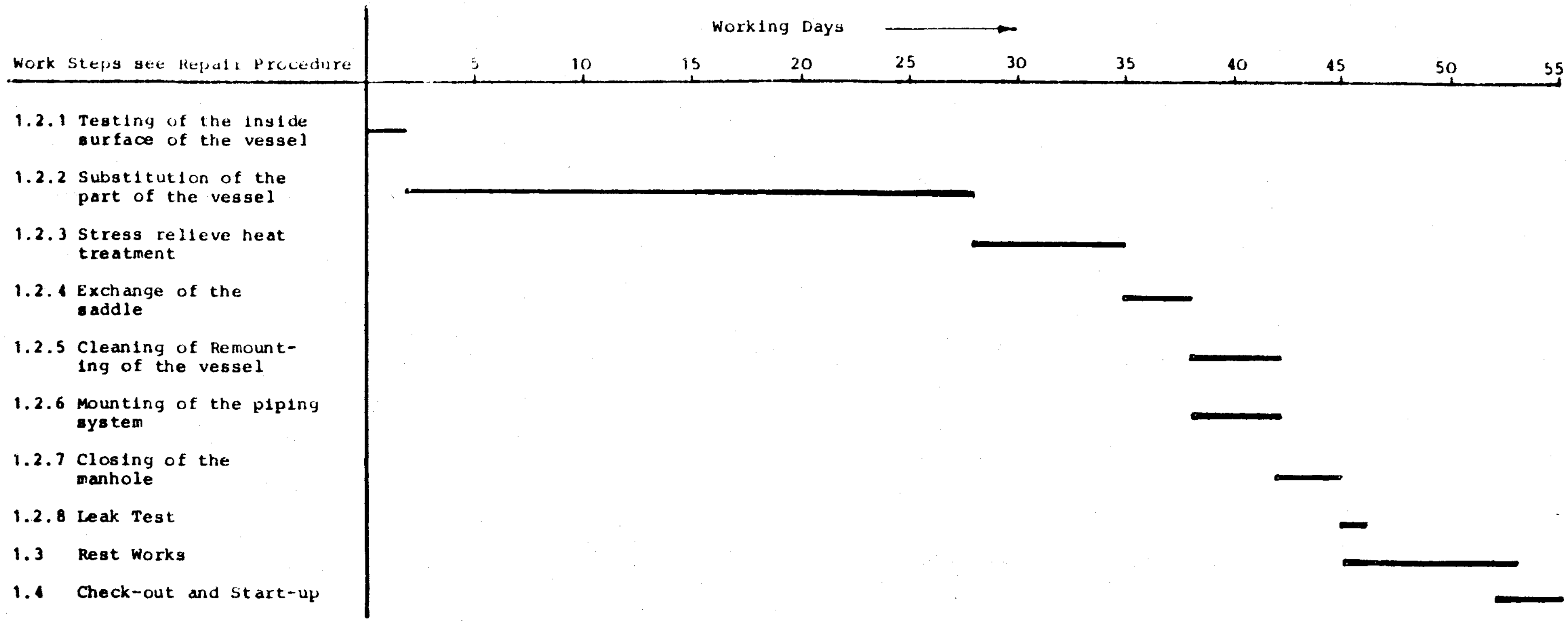
EF 3-501





gez. Hubinger Dat. 18. 12. 1982

Wärmebehandl. plan Nr. 501
heat treatm. drwg



Time Schedule for Repair of the
Cold Storage Vessel

IEA – SSPS PROJECT CRS

INTERATOM
INTERNATIONALE ATOMREAKTORBAU GMBH

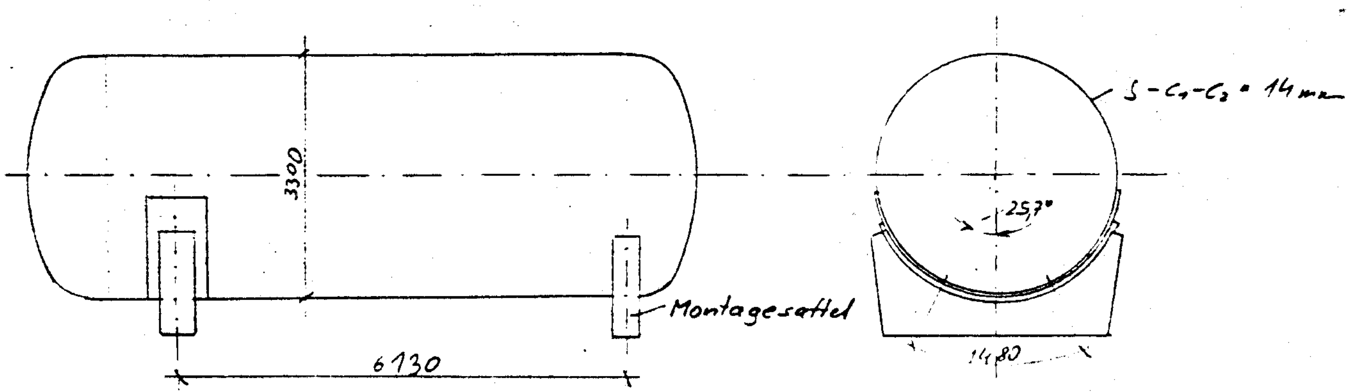
VOEST-ALPINE AG Finalbetriebe Linz	ALMERIA	Auftrags-Nr.: 57.32. 1 76 35 Seite 9 von 11

Art der Änderung | Datum | Erstellt | Rev. 01 02 03 04

Genehmigt

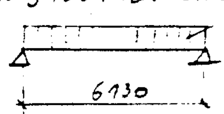
Verteiler:

4. Berechnung.
Calculation



Behältergewicht: G ≈ 20 t (incl. Isolierung u. Heizelemente)
weight of vessel (including insulation and heating element)

4.1. Längsspannungen im Behälter beim Glühen.
Longitudinal stresses in the vessel during stress relieve heat treatment:



$$q = \frac{200000}{6130} = 32{,}6\ N/mm$$

$$M_{max} = \frac{32{,}6 \cdot 6130^2}{8} = 1{,}532 \cdot 10^8\ Nmm$$

$$J = \frac{\pi (D_a^4 - D_i^4)}{64} = \frac{\pi(3300^4 - 3272^4)}{64} = 1{,}951 \cdot 10^{11}\ mm^4$$

$$W = \frac{J}{1650} = 1{,}182 \cdot 10^8\ mm^3$$

$$\sigma_{max} = \frac{1{,}532 \cdot 10^8}{1{,}182 \cdot 10^8} = \underline{1{,}3\ N/mm^2}$$

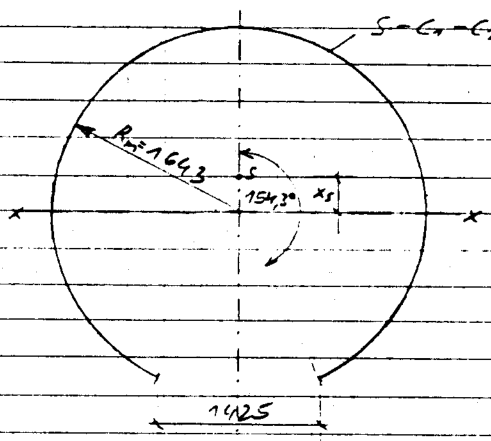
Die 1% Zeitdehngrenze (10000 h) beträgt bei 550 °C
The 1% time yield strength (10000 h) is $\sigma_{1/10000} = 60\ N/mm^2$ at 550 °C
noch $\sigma_{1/10000} = 60\ N/mm^2$. Daher erscheint die geringe
Therefore the low stress of $1{,}3\ N/mm^2$ is scrupless.
Spannung von $1{,}3\ N/mm^2$ unbedenklich.

Abteilung: TLS 16	Bearbeitet: Modlsperger Mad	Tel 9-50	Dat. 1982-11-19
	Geprüft:	Tel:	Dat

Art der Änderung / Item | Datum / Date | Erstellt / Prep. | Rev. 1 2 3 4

4.2 Längsspannungen im geschwächten Teil
longitudinal stresses in the cut-out zone

Es wird ein 1480 mm breiter Bereich ausgenommen.
An area of 1480 mm is cutted out



$$J_x = 2R^3\left(\frac{\cos\varphi_1 \cdot \sin\varphi_1}{2} + \frac{1}{2}\varphi_1\right) s$$

$$= 2 \cdot 1643\left(\frac{-0{,}901 \cdot 0{,}434}{2} + \frac{2{,}693}{2}\right) 14$$

$$= 1{,}43 \cdot 10^{11}\ mm^4$$

$$x_s = \frac{1643 \cdot 1425}{8849} = 264{,}6\ mm$$

$$J_{x_s} = 1{,}43 \cdot 10^{11} - 123886 \cdot 264{,}6^2$$

$$= 1{,}343 \cdot 10^{11}\ mm^4$$

$$W = \frac{J}{1745} = 7{,}7 \cdot 10^7\ mm^3$$

$$\sigma_{max} = \frac{1{,}532 \cdot 10^9}{7{,}7 \cdot 10^7} = \underline{20\ N/mm^2} < 180\ N/mm^2$$

Genehmigt: Approved:

Zulässige Spannung: $\sigma_{0,2\,20°} = 270\ N/mm^2$
allowable stress

$$\sigma_{zul} = \frac{270}{1{,}5} = 180\ N/mm^2$$

Verteiler: Copies:

Chapter I.II.II

Manufacturing and Installation-Program of a New Cold Storage Vessel LK01 BB01

Prepared by: VOEST ALPINE/INTERATOM

TVS-No.: 129646

Date: 82-11-25

Revision: 0

Approved by:

Contents

1 New manufacture at workshop of VOEST-ALPINE

1.1 Manufacturing procedure

The manufacturing procedure as shown in the attached time schedule is the following:

1. Material procurement
2. Manufaturing of bottoms
3. Welding of vessel
4. Welding internals
5. Stress relieving
6. Testing procedure
7. Cleaning procedure
8. Transportation to Site

1.2 Modification of design and fabrication

Manufacture of a new Cold Sodium
Storage Vessel with following variations:
(See VA-drawing Nr. 57.32.17634/8210, Rev. d)

a) Stress relieve heat treatment of the whole vessel in the workshop

b) Variation of the sodium inlet parts acc. to VA-dwg.nr. 57.32.17634/8210/1

c) Variation of the wall thickness (from 16 to 18 mm). This elevation of the wall thickness beyond the AD-requirements is to have more additional reserve for thermal streeses

2 Procedure of manufacture

The procedure of manufacture is similar to that of the original Cold Sodium Storage Vessel.
The nondestructive tests are performed after the stress relieve heat treatment. Pressure test and leak test are performed at the VA-workshop (a detailed inspection plan is in preparation).

A new saddle support will be manufactured and delivered by VAL.

3 Modified Drawings

The revised drawings of new cold storage vessel (drawing no. 57.32.17634/8210, Rev. d) as well as a detailed drawing of the modified down comer pipes inside the vessel (drawing no. 57.32.17634/8210/1 are attached).

4 Installation Plan for new Vessel on Site

Assumptions

- old cold storage vessel is disconnected from the piping system

- new cold storage vessel is ready on site with step No. 4

Work Steps

1. Disassembly

- dismantling of thermal insulation of the complete old storage vessel
- disassembly of the sodium piping system around sodium pump No. 1
- dissassembly of the sodium pump No. 1
- disassembly of the steel work at the east-side of the cold storage vessel (pump support structure, wall structure, greetings etc.) to a level between +3.00 m and -2.10 m.

2. Preparing of building and site

- preparing of a mounting trench beside the east-side wall of the sodium hall of appr. 14.00 x 5.50 m (see sketch drawing)
- cutting out of the concrete wall of the sodium hall east-side (beside the cold storage)
- preparing of the mounting trench with gravel (appr. 500 mm)
- installation of the steel rails between cold storage and mounting trench for a weight of appr. 20 tons

3 Moving of vessel out of the sodium hall

- fixing of both vessel supports with an additional steel structure
- installation of auxiliary vessel lifting construction and locking of vessel moving support

- lifting of the vessel (below the vessel supports) at both sites up to appr. 300 mm (horizontal)
- installation of the steel rails below the vessel supports and connection with steel rails to the mounting trench
- covering of the steel rails with teflon and pulling out of the vessel by lifting jacks into mounting trench
- lifting of the old storage vessel to a truck by crane (without the vessel supports)

4. Inserting of new storage vessel into the sodium hall

   - preparation of the new storage vessel for installation (has to be ready beside the mounting trench)
   - preparation of the new vessel fix support at the installation rails and fixing with the moving support (with the additional steel structure)
   - inserting of new storage vessel into the prepared supports by crane
   - covering of the steel rails with teflon and pulling in of the vessel by lifting jacks into the sodium hall
   - disassembly of the steel rails below the vessel supports
   - lowering of the vessel down to the concrete supports by lifting equipment
   - leveling and fixing of the vessel
   - disassembly of vessel support fixing equipment (additional steel structure) and vessel lifting construction

5. Repreparing of building and site

- disassembly of the steel rails between sodium hall and mounting trench
- closing of sodium hall wall and installation of the steelwork (pump support structure, wall structures, greeting etc.)
- reinstallation works of the mounting trench (preparation of the before existing conditions)

6. Installation of sodium system

- installation of the sodium pump No. 1
- installation of the sodium piping system around sodium pump No. 1
- connecting of sodium piping system to the cold storage vessel
- testing procedure
- installation of trace heating equipment
- installation of thermal insulation
- installation of electrical equipment
- closing of man-hole incl. inspections

7. Check-out of the installed systems and components

5 Time Schedule

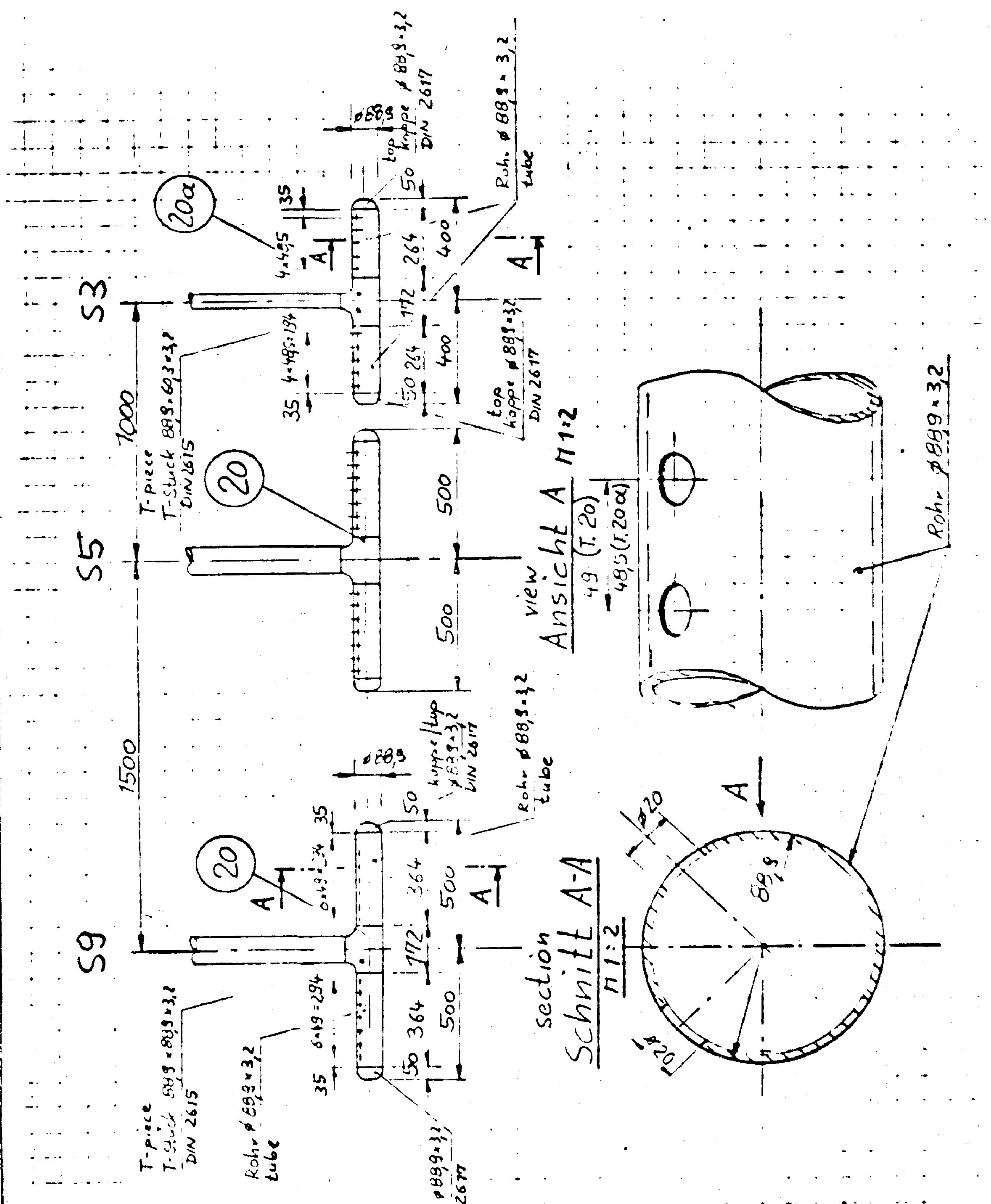
The attached time schedule indicates the complete manufacturing, transportation and installation procedure of a new cold storage vessel LK01 BB01.

To minimize the required time for material procurement the ordering of the necessary material will be sent out beginning of December 1982.

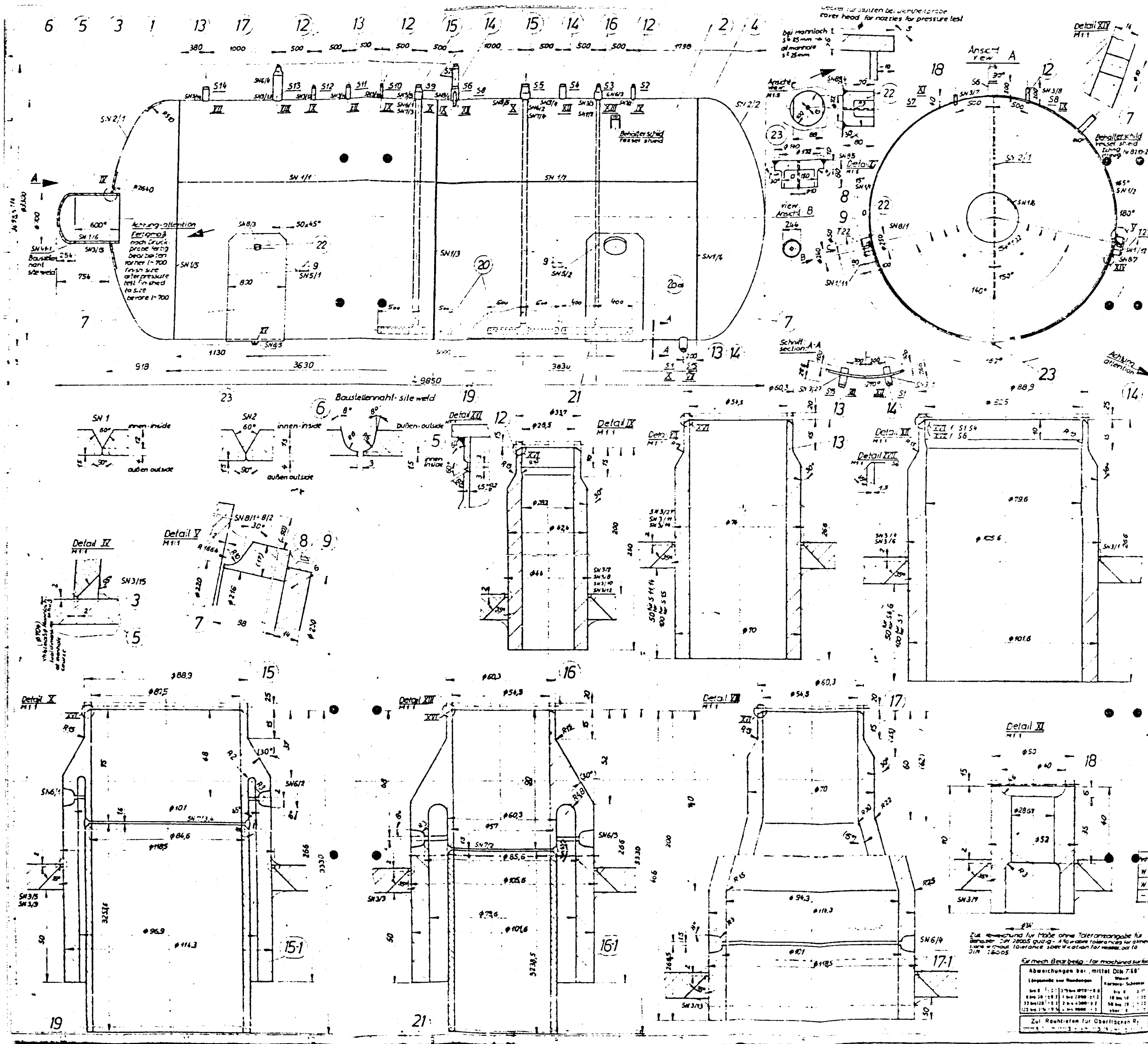
VOEST-ALPINE AG
Finalbereich Linz
Finished Products Division

CRS- ALMERIA
Kalter Na-Speicher
cold sodium storage vessel

Zeichng Nr
Drwg Nr
5732 17634
8210/1



gez. [signature] 23.11 1982



Stutzenliste - nozzle schedule

Bezeichg. Symbol	Stück piece	NW DN		Beschreibung - description
S1	1	80		LK01 - BR 01
S2	1	25		0G01 - BR 11
S3	1	50		LK02 - BR 03
S4	1	80		Füllstutzen - filling nozzle
S5	1	80		LK01 - BR 07
S6	1	80		Level indication Füllstandanzeiger
S7	1	25		Temp. indication Temp. anzeiger
S8	1	25		Pressure indication Druckanzeiger
S9	1	80		LK01 - BR 04
S10	1	25		0G01 - BR 24
S11	1	50		0G01 BR 25
S12	1	25		0G01 - BR 26
S13	1	50		0G01 - BR 14 safety nozzle
S14	1	50		0G01 - BR 13
S15	1	50		LK01 - BR 08

Bemerkungen - remarks

1. Zur Zeichnung gehören folgende Unterlagen
   the following belongs to this drawing
   a SP-Nr 1-8.9
   b Reinigungsplan 4, cleaning schedule 4
   c Zchng Nr - drawg Nr 0210-1, 0290, 0210-2, 0250-1, 0250-2
   d Berechnung - calculation Nr 2, Datenblatt Nr 2 - Data sheet No 2
2. Oberflächen - surfaces:
   a Bleche - plates: Ra ≤ 20 μm
   b Schweißkanten - weld edges Rt ≤ 30 μm
   c mech. bearb. Flächen - machined faces Rt ≤ 25 μm
   d alle Kanten entgraten - deburr all edges
   e SN - Oberflächen - SN surfaces Rt ≤ 40 μm
3. alle nicht gekennzeichneten SN und versenkten Kehlnähte a = 6
   all undimensioned SN and double groove a = 6 mm
4. SN ohne Schweißplan: Prüfung MF nach 8563, Abnahme K2
   SN without SP: surface MF examination acc. to 8563, inspection K2
5. Überlänge der Stutzen f. Druckprobe bei mech. Bearbeitung berücksichtigen, wird auf Baustelle abgetrennt. - during machining overlength of nozzles for pressure tests, the excess length will be cut off site.

7. Mindestwandstärken - mm thickness (ausgeführt - finished)
   Teil - part 1, 2, 5 s_{min} = 16 mm, Teil - part 6 s_{min} = 12 mm
   Teil - part 3, 4 s_{min} = 15 mm

Stück piece	Benennung nomenclature	Abmessung dimension	Teil part	Material material	WVS Nr	Anford.-stufe class-grade
1	Stutzen - nozzle	φ114,3/94,3 x 266,5	17,1	15 Mo 3	264 01P	1
1	Stutzen - nozzle	φ101,6/79,6 x 196	16,1	15 Mo 3	264 01P	1
2	Stutzen - nozzle	φ114,3/96,9 x 216	15,1	15 Mo 3	264 01P	1
1	Zentrierung - centering	φ 140 x 80	23	15 Mo 3	262 01	2
2	Zentrierung - centering	φ 100 x 80	22	15 Mo 3	262 01	2
1	Rohr - pipe	φ 60,3/54,6 x 3238,5	21		264.01A	3
3	Ausströmstücke flow-distributor	s. Zchn. Nr 5732.4 s. Drwg. No 8210/1	20/20a		264.01A	3
2	Rohr - pipe	φ 88,9/82,5 x 3253,5	19		264.01A	3
1	Temp-meßstutzen - temp. meas. noz.	φ 50/28,67 x 70	18		263 01	1
1	Sicherheitsstutzen - safety nozzle	φ 114,3/54,5 x 466	17		263 01	1
1	Komp-Stutzen - thermo sleeve	φ 101,6/54,5 x 266	16		263 01	1
2	Komp-Stutzen - thermo sleeve	φ 114,3/82,5 x 266	15		263 01	1
3	Stutzen - nozzle DN 80	φ 101,6/79,6 x 266	14		263 01	1
3	Stutzen - nozzle DN 50	φ 70/54,5 x 266	13		263 01	1
6	Stutzen - nozzle DN 25	φ 42,4/28,2 x 230	12		264 01P	1
~~3~~	~~Prallblech - baffle plate~~	~~17 x 400 x 400~~	~~11~~	15 Mo 3	262 01	3
~~6~~	~~Rippe - rib~~	~~14 x 66 x 300~~	~~10~~	15 Mo 3	262 01	3
2	Scheibe - disc	14 x φ 230	9	15 Mo 3	262 01	3
2	Poller - trunnion	17 x 98 x 732	8	15 Mo 3	262 01	2
2	Gurtblech - chord plate	14 x 800 x 4685	7	15 Mo 3	262 01	2
1	Korbbogenboden - semi-ell head	s = 14 D_A = 700	6	15 Mo 3	262 01	1
1	Mannlochschuß - manhole course	18 x 600 x 2149	5	15 Mo 3	262 01	1
1	Korbbogenboden - semi-ell head	s = 17 D_a = 3300	4	15 Mo 3	262 01	1
1	Korbbogenboden - semi-ell head	s = 17 D_a = 3300	3	15 Mo 3	262 01	1
1	Mantelschuß - shell course	18 x 3630 x 10317	2	15 Mo 3	262 01	1
1	Mantelschuß - shell course	18 x 3630 x 10317	1	15 Mo 3	262 01	1

2512.01

	Index	Geändert - revised	Datum	Name	Index		Geändert - revised	Datum	Name
W	e	1. Reparatur 1st repair			f	W	2. Reparatur 2nd repair		
W	b	nach IA after IA	79-11-16	Haug	d	W	nach IA - after IA	80-01-11	
W	a	Blechdicke geänd. plate thickn. revised	79-10-25	Haug	c	W	nach IA - after IA	79-11	

Abnahme durch - inspection by: TÜV, IA, VAL — RVS-CRS

Stückliste Nr: 82 — 110.100

	Datum	Name
	79-09-25	Haug
	79-09-28	

VÖEST-ALPINE AG
FINALBETRIEBE LINZ

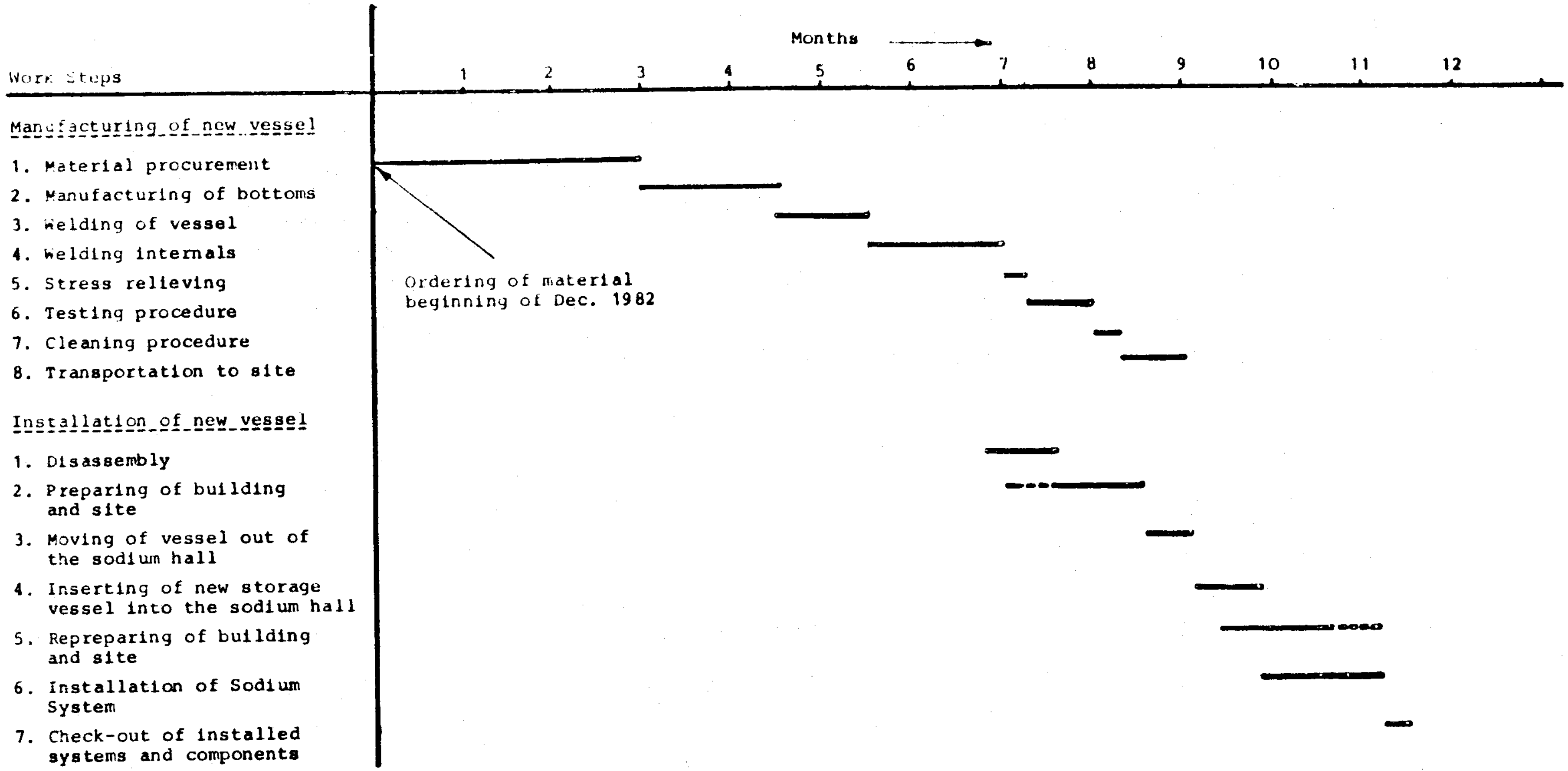
Maßstab scale: 1:25, 1:1

Besteller purchaser: Interatom

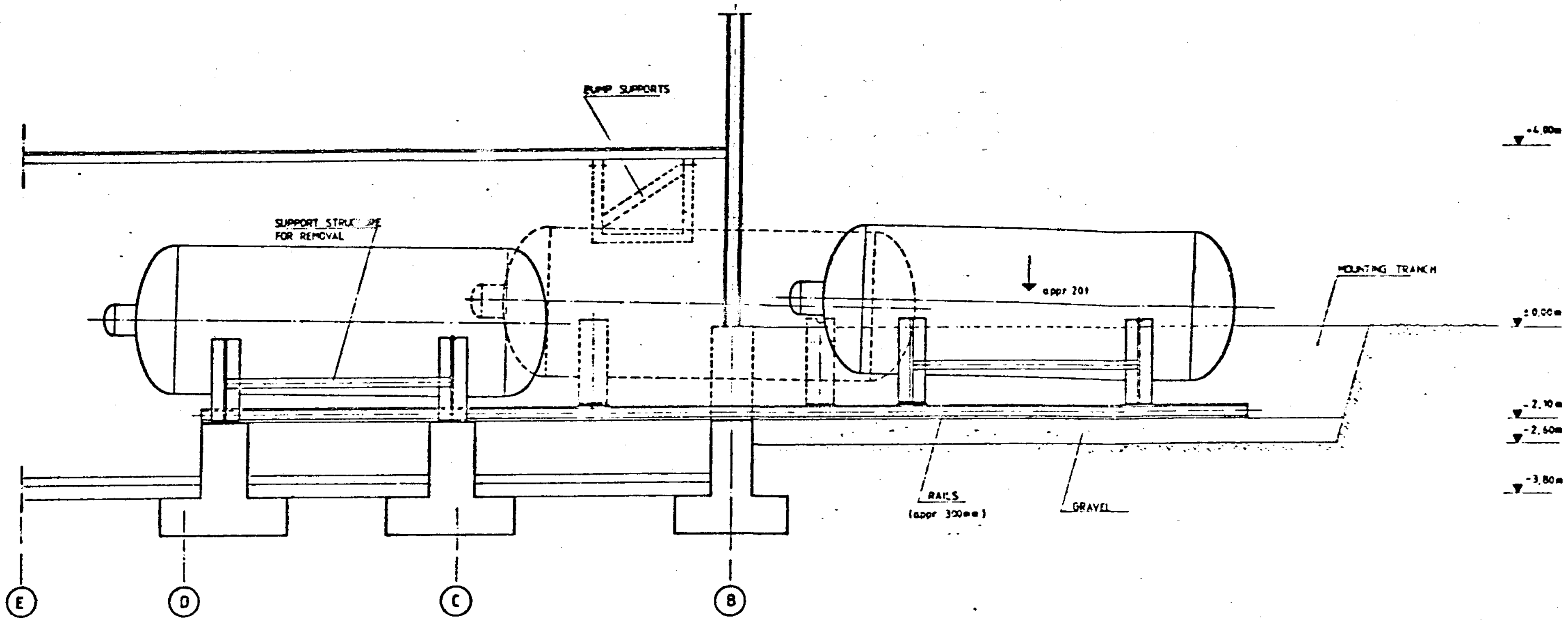
Bauvorhaben project: CRS - Almeria

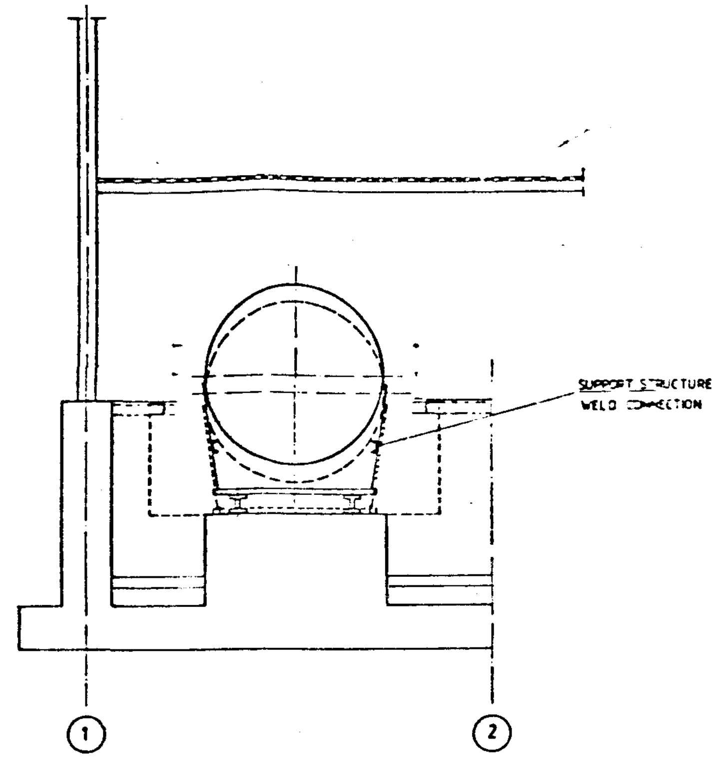
Zeichnung Nr: 57 32 17634 / 8210

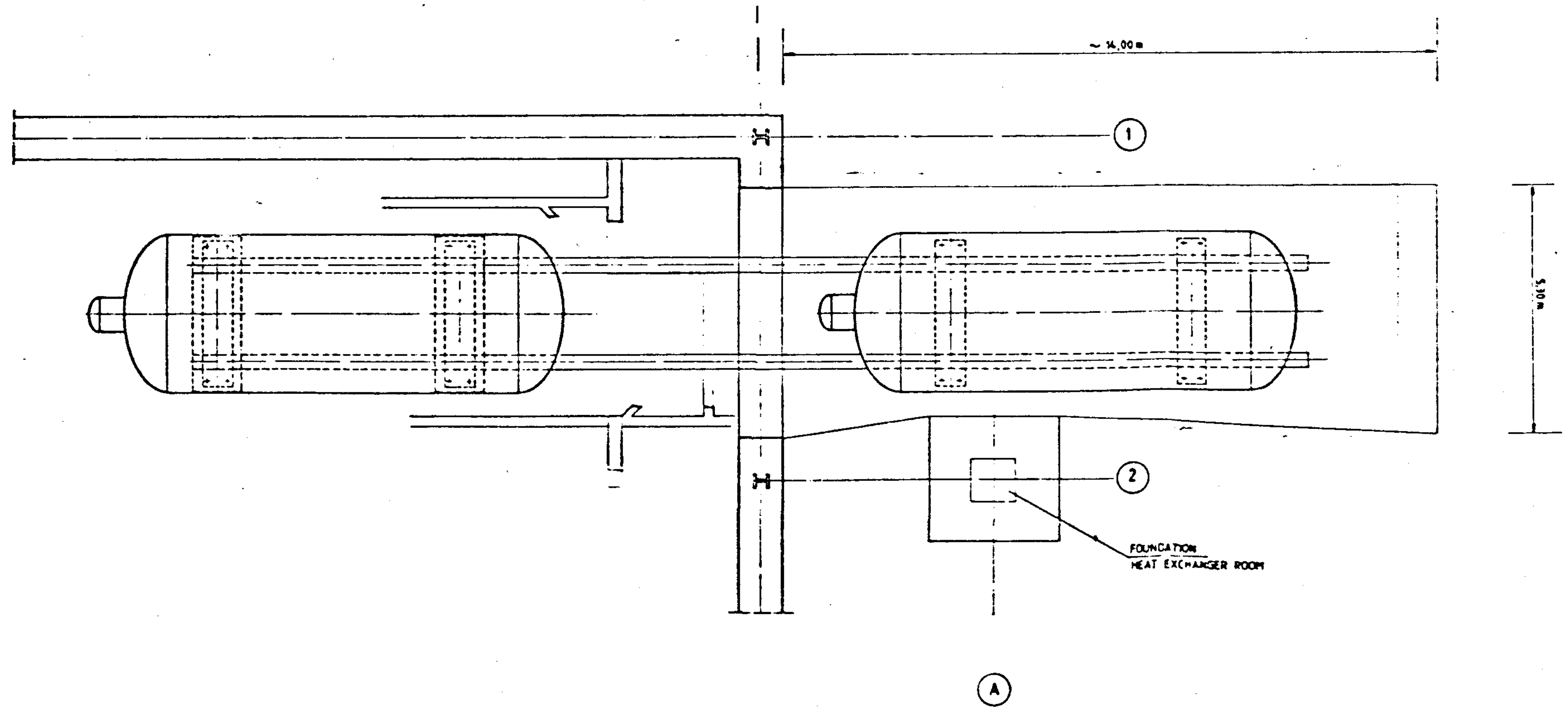
Kalter Na Speicher - [illegible] storage vessel



Time Schedule for Manufacturing
and Installation of New Sodium Vessel







ACC. DRAWINGS

CRS PLOT PLAN ±0,00m -3,30m CRS P01
CRS PLOT PLAN SECTION A-A, B-B, CRS P03
CRS PLOT PLAN SECTION C-C, D-D, E-E, F-F, CRS P04
INITEC DRAWING NO 5870 -0 E C2701 „B"
INITEC DRAWING NO 5870 20 E C2201 „B"
INITEC DRAWING NO 5870 -0 E C1302 „C"

1:50
10.11.82
T 123
INTERATOM

COLD STORAGE REMOVAL RECOMMENDATION

CRS 2423 127272 28

CRS P10

Chapter I.II.III
Repair Program of the Regenerating Vessel
LL01 BB01

Prepared by: VOEST ALPINE/INTERATOM
TVS-No.: 129646
Date: 82-11-25
Revision: 0
Approved by:

Contents

		Performed by
1	**Description of Repair**	
1.1	**Preparation Works**	
	- Dismantling of insulation of the Regeneration Vessel in the zone of the manhole nozzle	INTERATOM
	- Taking of material sample at weld no. 9/2	INTERATOM/TÜV
	- Temporary closure of the sample hole	INTERATOM
	- UT of the welds in the lower region of the regeneration vessel acc. to process inspection plan no. S05	INTERATOM/TÜV
	- Draining of sodium	INTERATOM
	- Cutting off the piping at nozzle no. 10	INTERATOM/VAL
1.2	**Repair Procedure**	
	- Cutting off the manhole cover	VAL
	- Temporary closure of the manhole	
	- abbreviation of the manhole shell course	
	- Preparation of the weld edges at weld no. 9/2	

VAL = VOEST ALPINE
TÜV = Techn. Überwachungsverein, Köln

Performed by

- Removing of the temporary closure
- Mounting and Welding of the manhole cover
- Testing during welding acc. to process inspection plan no. S05
- Grinding smooth and ground flush of the weld no. 9/2
- Stress relieve heat treatment (if necessary) similar to cold sodium storage vessel
- Mounting and welding of the piping at nozzle no. 10
- Testing after welding acc. to process inspection plan no. S05

1.3 Rest Works

- Reinstallation of trace heating and thermal insulation	INTERATOM
- Reinstallation of electrical cabling	

1.4 Check-out and Start-up — INTERATOM

- Check of trace heating system
- Switch-on of trace heating system

		Performed by
2	Manufacture in Workshop (Replacing part no. 5 and 15 acc. to dwg. no. 57.32.17634/822o)	VAL

- pressing of the "Korbbogen" bottom part no. 5
- welding of part no. 15 to part no. 5
- testing acc. to process inspection plan no. S04

3 Testing Plan

3.1 Semifinished Products

- Korbbogen bottom: acc. to spez. WVS 262,UT of the welding zones, SC testing of the prepared weld edges
- piping for part 15: acc. to specification WVS 264 A,SC testing of the prepared weld edges

3.2 Process Inspection at VA

acc. to process inspection plan no. S04

3.3 Process Inspection at the Site

acc. to process inspection plan no. S05

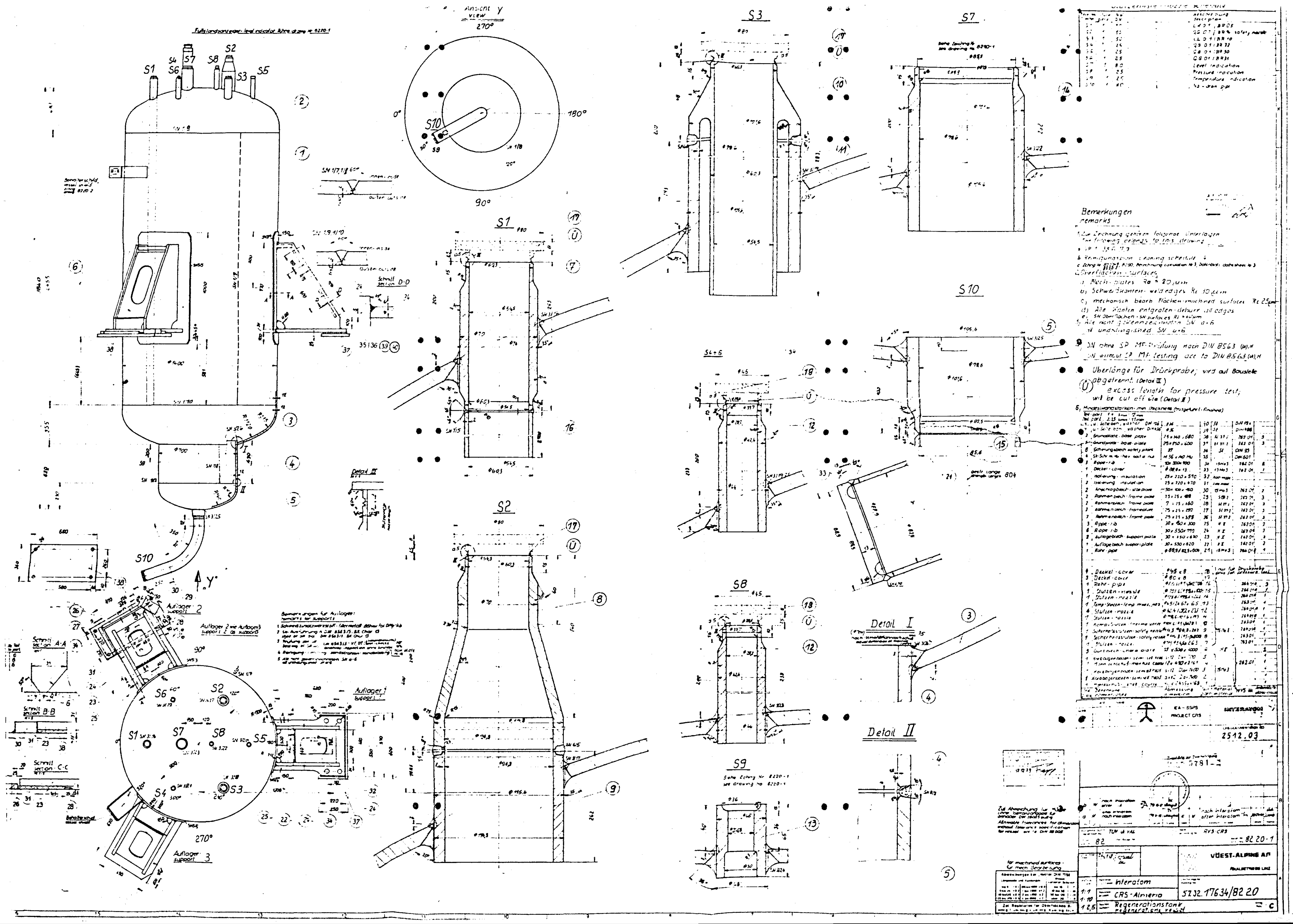
4 Time Schedule

The complete repair work of the regeneration vessel will be performed within appr. 4 weeks in parallel to the repair procedure of the cold storage vessel.

The repair work can start immediately after fabrication of the new "Korbbogen" bottom at VAL's workshop.

5 Appendix

- Drawing of the regeneration vessel (No. 57.32.17634/8220)
- Process inspection plan no. S04
- Process inspection plan no. S05


S1
S2
S3
S4
S5
S6
S7
S8
S10
Ansicht Y
view
270°
0°
180°
90°
S1
S2
S3
S4+6
S7
S8
S9
S10
Detail I
Detail II
Detail III
Schnitt A-A
section A-A
Schnitt B-B
section B-B
Schnitt C-C
section C-C
Schnitt D-D
section D-D
Auflager 1
support 1
Auflager 2
support 2
Auflager 3
support 3
Bemerkungen
remarks
Zur Zeichnung gehören folgende Unterlagen
The following belongs to this drawing
b Reinigungsplan cleaning schedule
Oberflächen - surfaces
a) Blech - plates
b) Schweißkanten - weld edges
c) mechanisch bearb. Flächen - machined surfaces
d) Alle Kanten entgraten - deburr all edges
e) SN Oberflächen - SN surfaces
Alle nicht gekennzeichneten SN a=6
all undistinguished SN a=6
SN ohne SP MF-Prüfung nach DIN 8563 (W), H
SN without SP MF-testing acc. to DIN 8563 (W), H
Überlänge für Druckprobe; wird auf Baustelle abgetrennt. (Detail III)
excess length for pressure test; will be cut off site (Detail III)
Mindestwandstärken - min. thickness (ausgeführt - finished)
Grundplatte - base plate
Scherungsblech - safety plate
Deckel - cover
Rohr - pipe
Stutzen - nozzle
Isolierung - insulation
Rippe - rib
Auflageblech - support plate
Rahmenblech - frame plate
2512.03
5781-2
nach Interatom
after Interatom
TÜV u. VAL
RVS-CRS
82
8220-1
VÖEST-ALPINE AG
Interatom
CRS-Almeria
5232.17634/8220
1:1
1:10
1:2,5
Regenerationstank
regeneration vessel
C

FACHLEUCHKERI...TOREN
Fachget. d Leistung Leitoren

Hersteller / manufact.	VOEST-ALPINE AG
Werk Nr / order-no	57.32 17634
Zeichnung Nr / drawing no	8220
Benennung / nomenclature	CRS - ALMERIA regenerations vessel
Spezifikation des Bestellers / specification no	CRS SOLAR POWER PLANT 2.4.2.4

PROCESS INSPECTION PLAN **Bauprüfplan** 504

Prüfplan Nr / examination ... no

Revision

Seite 1 von 1

Druck / pressure

Temperatur / temperature

Besteller / customer: INTERATOM

Projekt / project: CRS - ALMERIA

Anlageteil / part: Regenerationstank / regenerations vessel

Auftragsnummer des Bestellers / P. order no

Prüfumfang und Nachweiszusammenstellung / Typ of inspection and list of records

Benennung des Prüfteiles / check part		Kontrolle APZ / control of mat. cert.	Stempelkontrolle / control of marking	Maßkontrolle / dim. control	Prüfung auf zeichnungsgem. Ausführung / vis control of the constr. work	OR-Prfg Schweißk. / SC-test weld edges	OE-Prfg fert. Naht / SC-test weld seam	Sichtkontr. / VT	Maßkontr. / dim. testing	US Prfg der Schweißk. des Bleches / UT weld flanks	US Prfg der SN / UT weld seam	Reinheitskontrolle / cleanliness control
Korbbogenboden / Korbbogenbottom	57.32 17634 8220	H,K1,T2	H,K1,T2	H,K1,T2	H,K1							H,K1,T2
Rohrstück / piping	"	H,K1,T2	H,K1,T2	H,K1,T2	H,K1							H,K1,T2
SN 3/25 / weld no 3/25						H,K2,T1	H,K2,T1	H,K1,T2	H,K1,T2	H,K2,T1		
SN 9/2 / weld no 9/2						H,K2,T1						
SN 6/7 / weld no 6/7						H,K2,T1						

Erfüllungszeichen
x = erfüllt
O = sinngemäß erfüllt
— = nicht erfüllt

H · Hersteller
K_1 · Interatom
K_2 · IA (Teilnahme vorbehalten) (in own oppinion)
T_1 · TÜV / T_2 · TÜV (Teilnahme vorbehalten) (in own oppinion)

den 19.11. 19 82
Hubinger
Hersteller

den ____ 19__
Besteller

den ____ 19__

AEG E 21 8210 1 306/0171

FACHBEREICH KERNREAKTOREN
Fachgebiet Leistungsreaktoren

Hersteller / manufact. VOEST-ALPINE AG Werk Nr / order-no 57.32. 17634 Zeichnung Nr / drawing-no 8220	PROCESS INSPECTION PLAN **Bauprüfplan** 505 Prüfplan Nr. / examination-pl no — Revision — Seite 1 von 1	Besteller / customer INTERATOM	Projekt / project CRS - ALMERIA Anlageteil Regenerationstank part regenerations-vessel Auftragnummer des Bestellers / P. order no

Benennung / nomenclature: CRS ALMERIA regenerations vessel

Spezifikation des Bestellers / specification no: CRS SOLAR POWER PLANT 2.4.2.4

Druck / pressure:

Temperatur / temperature:

Prüfumfang und Nachweiszusammenstellung / Typ of inspection and list of records

Benennung des Prüfteiles / check part	Maßkontrolle / dimension testing	Kontr. auf zeichnungsgerechte Ausführung / test of drawings	OR Prüfung Schweißk. / SC test weld edges	OR Prfg fertige Nähte / SC test of welds	US Prfg SN Zone / UT SN-zone	Sichtkontr. / visuell testing	Maßkontr. / dim. testing	US Prfg fertige Nähte / UT of welds	RX	Dichtheitsprfg. / leak test
SN 1/8 weld no 1/8								H, K2, T1		
SN 1/10 weld no 1/10								H, K2, T1		
SN 1/17 weld no 1/17								H, K2, T1		
SN 9/2 weld no 9/2	H	H	H, K2	H, K2, T1	H, K2	H, K1, T2	H, K1, T2	H, K2, T1		
SN 6/17 weld no 6/17	H	H	H, K2	H, K2, T1		H, K1, T2	H, K1, T2		H, K2, T1	
Regenerationstank regenerations vessel										H, K2, T1

Erfüllungszeichen
x = erfüllt
O = sinngemäß erfüllt
— = nicht erfüllt

H · Hersteller
K_1 · Interatom
K_2 · IA (Teilnahme vorbehalten) (in own oppinion)
T_1 · TÜV / T_2 · TÜV (Teilnahme vorbehalten) (in own oppinion)

den 19. 11. 19 82 Kubinger
Hersteller

den 19

Besteller

den 19

AEG-E 2010 1.806/0171

CHAPTER I.III

Additional Investigations

Chapter I.III.I

Reasons for Material Selection

Prepared by: INTERATOM
TVS-No.: 129646
Date: 82-11-25
Revision: 0
Approved by:

Contents

1 Experience gained with 15 Mo 3-Steel as material used in sodium systems

1.1 Introduction

In the weld zone of the cold storage tank of the CRS-Almería (15 Mo 3 steel) sodium leakages occured. On the background of the operational boundary conditions of this cold storage tank relevant experiences concerning this type of steel as well as the closely connected group of materials of low alloy steels used for sodium systems are compiled.

1.2 Features of the material

The material 15 Mo 3 belongs to the group of low-alloy, creep-resistant steels according to DIN 17155 (table 1). Containing max. a 0,25 % Cr and approx. 0,3 % Mo it has an intermediate position with regard to alloy between the different types of low-alloy steel.

This steel is suitable for operating temperatures up to 530 °C, it is used in a normalized condition according to DIN 17155, for wall-thicknesses of 10 t 20 mm and more a preheating or a stress-free annealing is recommended concerning welding procedures.

1.3 Experiences regarding suitability for sodium systems

The creep-resistant, low-alloy steels with sufficiently high strength factors are mainly used for the low-temperature range at about 300°. Table 2 presents the respective examples; the fact, that this material is used for foreign sodium-cooled reactor systems should be underlined.

As shown in table 2, the periods of practical application, during which the creep-resistant steels proved good, exceed by far the operating times of the plant in Almería till the first sodium leakage. The proof in service of this material or other similarly low-alloy steels for cold trap with inlet-temperatures of about 250 °C, i. e. with higher oxygen content in sodium, illustrates above all the good corrosion resistance of iron-base alloys used for sodium system.

An in house collection about damages in sodium-systems holding approx. 60 cases does not mention any damage on low-alloy materials.

1.4 Aspects of corrosion when using 15 Mo 3 for sodium systems

Corrosion marks due to sodium are caused by small solubility differences of the alloy elements at the maximum and minimum system temperatures. Therefore, in the hot zone of the circuit steel is dissolved at a rate of < 10 µm/year; in the cold zones a deposit coat is constituted due to oversaturation at a similar rate.

In addition to that,sodium, as an inert medium joins construction materials of different carbon activity and thus permits a temperature dependant diffusion compensation, which, in general, goes from the low-alloy steels in the austentic CrNi Steels. Below 300 °C, however, these reactions do not have any effect due to temperature.

Proper concerted corrosion-investigations concerning the two materials HI and 13 CrMo 44, which are lower alloyed and higher alloyed, respectively, as 15 Mo 3 and belong to the same group of material, confirm the excellent corrosion properties of this steel group as to sodium.

Figure 1 shows some examples of the material H1 after 3.000 h of exposure in a sodium circuit at 400 °C and at the same cleaning conditions as in Almería.
Micro hardness tests confirm that in this temperature range practically no carbon-alterativ occured in the material.

Even under sodium conditions with extreme pollution-concentrations, iron base alloy in general proved their stability. This is proved by the experience from the use of this steel for devices (cold traps), which are used as sinks for pollutions in sodium systems neither from the operation of the coldtraps nor from the inspection of the routinely emptied or cleaned components hints results which would give rise to doubts concerning the corrosion resistance for the low-alloy steels. In this case the KNK cold trap made from 15 Mo 3 is to be specially mentioned.

Even corrosion due to the reaction of supposed residual humidity at the first filling of the plant with sodium can be excluded, because prior to the filling the plant is heated with dry inert gas.

As a conclusion it is to be retained that from a view point concerning corrosion no indications result which oppose to a use of this steel in sodium

1.5 General experiences with respect to processing

In comparison to high-strength materials, creep-resistant steels are distinguished by good working properties. When welding 15 Mo 3 material of a thickness of more than 10 mm, DIN 17155 recommends a preheating to 200 °C and in the case of stress-free annealing a temperature range of 600 °C to 650 °C is mentionned. The modification draft of this German Standard, dated November 1981, reduces the temperature range of stress-free annealing to 530 °C to 620 °C. According to the Mannesmann material specification sheet no. 405 B, dated December 1972, a stress-free annealing is recommended after welding procedures of wall-thickness of approx. 20 mm. In the case of unfavorable geometric marginal conditions Cerjak/ 1 /, accordings to the KWU-experience, points out that in the case of insufficient preheating there is a risk of cold cracking when welding. Due to the special stress-conditions such cracks were only discovered several days after the welding procedure. They appear partly as an intercrystalline and partly as an transcrystalline fracture.

1.6 Estimation of the max. amount of Na OH at vessel inside surfaces with rest Humidity

For estimation of the max. expected Na OH Corrosion in the cold storage vessel (15 Mo 3) of the CRS plant the following boundary conditions have been defined:

- the vessel has been dried by heating-up (150 °C) with vented Argon. The rest humidity at the complete inner surface of appr. 100 m² consists of mono molecular water films (appr. 10 - 100 times more conservative compared with real conditions). The resulting water ammounts to appr. 2,8 x 10^{-2} cm³.

If one assumes under conservative considerations that a small rest volume of 1 m³ sodium reacts completely with the total amount of water a Na OH concentration of 3.03×10^{-6} % Na OH will be the result.

For this very low Na OH concentration a corrosion of the material is not to be expected.

1.7 Post-Inspection of a Na draining vessel at the internal bottom area

To investigate probable corrosion effects at the inner vessel surface caused by contaminated sodium a 10 years operated Na draining vessel made from 10 CrMo 910-steel (operational data: 200/300 °C) was inspected in detail.

The effects have been concentrated beside the basis material analysis on the analysis of a circular weld seam and its heat effected zone situated at the bottom area of the vessel.

The results of this inspection can be summarized as follows:

- the weld seam as well as adjacent areas have been grinded at the inner surface before filling with sodium; the grinding grooves are completely preserved after 10 years contact with sodium and thus document even when only seen by the unaided eye the lack of any corrosion effect (see fig.2).

- the cross microsection of the weld seam proves the faultless condition of the seam as well as the heat effected zone, no corrosion effects can be detected.

1.8 Summary

Based on the generally found experimental background concerning low-alloy steels used for sodium-systems we can retain that this group of steels, the quality 15 Mo 3 included, has proven to be fully up to the mark. This confirms, that within the limits of the assigned admissible temperatures, the group of the mentionned steels is rentable for operation in sodium-systems.

/ 1 / Cerjak, H. et. al.
Kaltrisse beim Schweißen niedriglegierter Stähle
- Erscheinungsbilder, Ursachen, Abhilfen
VGB Kraftwerkstechnik 62 (1982) 318 - 324

Tabelle 1 Chemische Zusammensetzung (Schmelzenanalyse)

Stahlsorte		Chemische Zusammensetzung in Gewichtsprozent												
Kurzname	Werkstoffnummer	C	Si	Mn	P max.	S max.	Al_{ges}	Cr	Cu max.	Mo	Nb max.	Ni max.	Ti max.	V max.
UH I	1.0348	≤ 0,14	–	0,20 bis 0,80	0,035	0,030	–	≤ 0,30	–	–	–	–	–	–
H I	1.0345	≤ 0,16	≤ 0,35	0,40 bis 1,20	0,035	0,030	0,020 bis 0,070	≤ 0,25 1), 2)	0,30 1), 2)	≤ 0,10 1), 2)	0,01 2)	0,30 1), 2)	0,02 2)	0,03 2)
H II	1.0425	≤ 0,20	≤ 0,35	0,50 bis 1,30	0,035	0,030	0,020 bis 0,070	≤ 0,25 1), 2)	0,30 1), 2)	≤ 0,10 1), 2)	0,01 2)	0,30 1), 2)	0,02 2)	0,03 2)
17 Mn 4	1.0481	0,14 bis 0,20	0,20 bis 0,40	0,90 bis 1,40	0,035	0,030	0,020 bis 0,070	≤ 0,25 1), 2)	0,30 1), 2)	≤ 0,10 1), 2)	0,01 2)	0,30 1), 2)	0,02 2)	0,03 2)
19 Mn 6	1.0473	0,15 bis 0,22	0,40 bis 0,60	1,00 bis 1,60	0,035	0,030	0,020 bis 0,070	≤ 0,25 1), 2)	0,30 1), 2)	≤ 0,10 1), 2)	0,01 2)	0,30 1), 2)	0,02 2)	0,03 2)
15 Mo 3	1.5415	0,12 bis 0,20	0,15 bis 0,35	0,40 bis 0,90	0,035	0,030	≥ 0,050	≤ 0,25 2)	0,30 2)	0,25 bis 0,35				
13 CrMo 4 4	1.7335	0,08 bis 0,18	0,15 bis 0,35	0,40 bis 1,00	0,035	0,030	≥ 0,070	0,70 bis 1,10		0,40 bis 0,60				
10 CrMo 9 10	1.7380	0,06 bis 0,15	0,15 bis 0,50	0,40 bis 0,70	0,035	0,030	≥ 0,070	2,00 bis 2,50		0,90 bis 1,10				

1) Die Summe der Gehalte an Cr, Cu, Mo und Ni darf nicht größer als 0,70 % sein.

2) Die Einhaltung dieser Grenzwerte ist nur nach besonderer Vereinbarung nachzuweisen.

Table 2: Application of low-alloy heat resistant steels in Na-facilities

Facility	Component	Start-up	Operat./design temperature	Material	Volume (m^3)	
APB/RSB	Na-vessel 1655	1971	500 °C	15 Mo 3	84	
"	Na-vessel 1656	1971	500 °C	15 Mo 3	84	
"	Na-vessel 4347	1971	200/300 °C	H II	5,3	
"	Na-vessel 4357	1971	200/300 °C	H II	1,3	
KNK	Primary cold trap	1970	ca. 250 °C	15 Mo 3		
KNK	Secondary cold trap QU1K3	1970	ca. 250 °C	15 Mo 3		
SPX	Fuel element storage vessel	1985	ca. 400 °C	15 Mo 3		
SNR 300	Draining vessel	1985	230/500 °C	15 Mo 3	each 37 t dead weight	10 pieces
"	Leakage collecting vessel	1985	± 70 und 230/500 °C	15 Mo 3	each 63 t dead weight	
"	Leakage draining system	1985	230/500 °C	15 Mo 3		

SCK Bild 25 143

sodium side with particles
diffusion layer (4 µm)
eutectic-depleted zone (100 µm)
matrix

Pr. Nr. d 400 -2 -7 (2,7)
slantwise 1:10 magn. 200
5 sec. 2 % nital

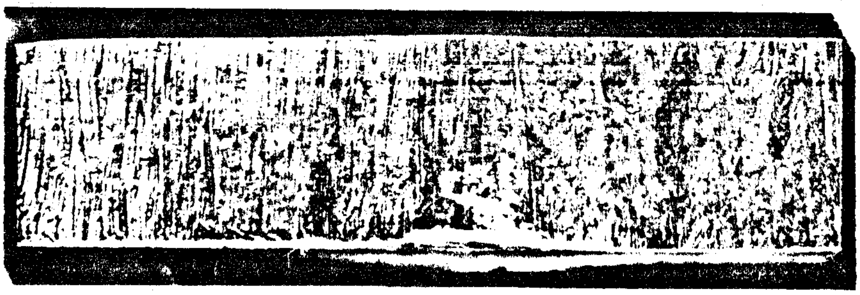
WERKSTOFF HI Kesselblech nach
3090 h, Natrium, 400 °C, Abkühlbereich

Fig. 1

INTERATOM
INTERNATIONALE ATOMREAKTORBAU GMBH

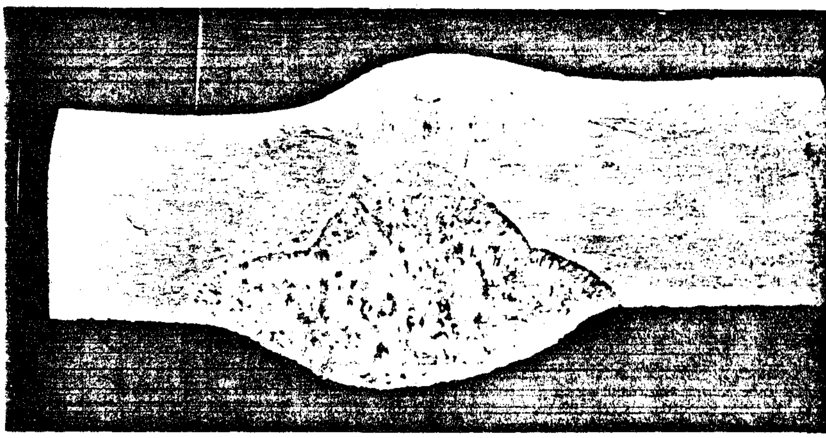
Bildseitenblatt

Fig. 2



B.1

Innenseite des Bodens mit herstellungsbedingten Schleifriefen (V= 3:1)



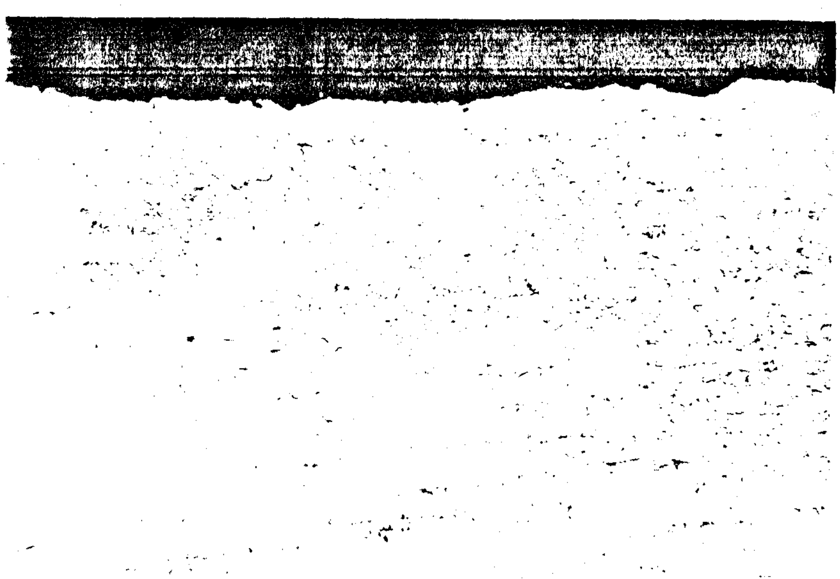
B.2

Innenseite

Schweißnaht im Bodenbereich (V= 3:1)

SG

SL



B.3

Innenseite des Bodens mit SG und WEZ (V= 100:1)

SG ≙ Schweißgut
SL ≙ Schmelzlinie

Bild-Nr.	Probe-Nr.	Schliff-Nr.	Vergroß.	Atzung	Film-Nr.	Bearbeiter	Datum
1	II a	5323	3:1	keine	R 421	Müller	22.10.82
2	"	"	3:1	"	"	"	"
3	"	"	100:1	alkoh. HNO_3	"	"	"

Versuchsbezeichnung: Nachuntersuchung Ablaßbehälter, 10CrMo 910 (5MW-Anlage)

Versuchsleiter: H. Grosser

Untersuchungsschwerpunkt: Na - seitige Befunde

CHAPTER I.III.II

Analysis of Material Samples of the Sodium Vessels (preliminary results)

Prepared by: INTERATOM
TVS No.:
Date: 82-11-25
Revision: 0
Approved by:

Contents

1 Analysis of Material Samples

According to the investigation procedure agreed upon with Operating Agent the material investigations are to be performed under the responsible conduction and at the laboratories of the TÜV in Cologne.

After the transport of the samples to Bergisch Gladbach the cutting and preliminary preparation of the samples as parts of the extracted vessel section have been performed on November 22/23, 1982. On November 24, the analysis work at the TÜV laboratories started.

The first results and comments from INTERATOM's side are given in the following paragraphs.

1.1 First Results of the Regenerating Vessel Failure

The first results of the investigation of the single crack at the bottom weld seam are:

- the crack is running crosswise to the weld seam
- the crack occured at a point where the two ends of the root layer of the weld seam (TIG-welded) met each other, at the crack point there was no penetration of the root
- the wall thickness of bottom and cylindrical stud was different which obviously has complicated the welding, small amounts of welding material have been found fixed to basis material and weld seam
- black coloured corrosion products could be detected at the crack surface of the outside part of the crack; this could be explained by the reaction of the leaking sodium with the air humidity and cleaning water from outside; the colour of the corrosion products was lighter (brown) to the inner part of the crack which indicates less corrosion

- the crack was a mixture of trans- and intercristalline fissures which have been detected formerly, too during analysis of drilling samples of the cold storage vessel and must not be the result of stress corrosion but of corrosion due to sodium/water reaction.

1.2 First Results of the Cold Storage Vessel Failures

The first results with respect to the failures of the cold storage vessel are:

- one crack in the bottom part of vessel wall was detected to run directly from the slot around the web plate of the baffle plate to the connection weld seam between vessel wall and repair stud
- the web plates under the baffle plate have been detected to be non-parallel inclined in contradiction to the original design
- during the division of the extracted material section a remarkable distortion of the edges due to stress relief was noticed
- with respect to first results after breaking the crack under the web plate this crack is also of trans- and intercristalline character which has been noticed formerly, too (REM-method applied).

CHAPTER I.III.III

Cold Storage Vessel
Inside Inspection

Prepared by: INTERATOM
TVS No.:
Date:
Revision:
Approved by:

The inspection has just been started.
Results will be issued as soon as possible.

Chapter I.III.IV

Inspection Results of Regenerating Vessel

Prepared by: INTERATOM
TVS-No.: 129646
Date: 82-11-25
Revision: 0
Approved by:

Inspection Results of Regenerating Vessel

The ultrasonic test inspection at the lower part of the regenerating vessel (both lower dished heads), which had been performed on Nov. 19th, 1982 came to the following result

"not to be recorded indications"

in line with AD-rules HP 5/3 (see attached annex).

The used testing equipment and the testing procedure are also shown in this a. m. annex.

INB
INTERNATIONALE NATRIUM-BRUTREAKTOR-BAU GESELLSCHAFT MBH

Ultraschallprüfbericht

Ident-Nummer	P	Ä	B	I
			7	3

Blatt 3 von 3 Blatt

Auftraggeber

Kernkraftwerk Kalkar (SNR-300)

Anlageteil: Regenerationstank

Baugruppe: Mannloch SN 9/2, 1/10, 3/26, 1/8

Anlagen-Kennzeichen-System: 0 1 2 3 4 5 6 S C

Zeichnung Nr.: 82206

Einzelnachweis lfd. Nr.:

Proj.-Gl. Syst.: 2423 HA-Nr. 1100 Proj.-Gl.-Nr.

F K Fremdangabe F C

Auftragnehmer: Fa. Voest-Alpine

Bestell-Nr.:

Auftrag-Nr.: 5732/17634

Spezifikation:

RVS CRS 11 Rev A

Spezif.-Nr.:

Prüfung:

Ort: Taberner

Datum: 18.11.82 – 19.11.82

Prüfer: H. A. Müller

Prüfschritt-Nr.:

Teilnehmer:

H. A. Müller

Prüfgegenstand	Werkstoff	Abmessungen
Regenerationstank Mannloch-bereich 100% Klöpperboden, Ring, Klöpperboden bis einschließlich SN 1/10	15 Mo 3	Wanddicke 12 mm

Prüfköpfe u. Frequenz: MWB 45° N4; MWB 70° N4

Prüfgerät: USM 2

Anforderungen: in Anlehnung an AD-Merkblatt HP 5/3

Geprüfte Zone: 100% des gesamten Bereiches bis SN 1/10 auf Längs- und Querfehler.

Einstellung des Gerätes:

Prüfbereich: 0 – 100 mm SW

Verstärkung: nach AVG-Diagr. Erg Ø 1.0 mm

Auflösung: /

Unterdrückung: /

Imp.-Stärke: /

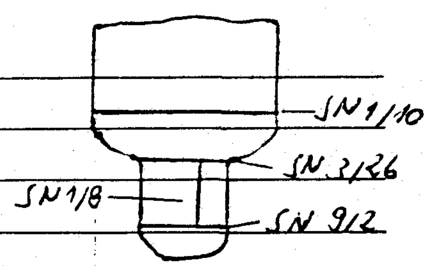
Ankopplung: Kleister

Prüfkopf ~~angeschliffen~~/nicht angeschliffen*

Oberflächenbeschaffenheit: beschliffen

Ergebnis der Prüfung:

Keine registrierpflichtigen Anzeigen



den 19	den 19.11.82 19	den 19
Werkssachverständiger	Qualitätsstelle des Auftraggebers* der INB	Überwacher

16314 (4490—7409) (h) Nichtzutreffendes bitte streichen

Chapter I.III. V

Cold Storage Vessel
Stress Calculation

Prepared by: INTERATOM

TVS-No.: 129646

Date: 82 - 11-25

Revision: 0

Approved by:

Contents

1 Conclusion

- The design of the cold storage is okay considering mechanical loads as dead weight and inner pressure.

- The construction of the baffle plate was very unadvantageous in view of the impressed thermal loadings. There is a high probability for an occuring fialure in the area of the attachment of the baffle plate to the vessel wall due to thermal loadings, also if additional uncertainties as temperature gradients across the vessel wall, multiaxiality, weldment effects etc. are not been considered.

- Apart from the disadvantageous design of the baffle plate, the vessel wall could not been failed due to the occured thermal transients. This result is in accordance with / 1 /.

- Significant improvements could be achieved in the new design by

  . temperature difference reduction by mixing tees
  . damping of temperature level as hot sodium inlet is far from vessel wall
  . avoiding any geometrical discontinuities in the vessel wall

2 Old design

2.1 Loading conditions

- inner pressure (design): 7,5 bar
- Dead weight: see chap. 2.3.2
- Thermal loading: see chap. 2.3.3
  . temperature level
  . transient conditions

2.2 Material behavior

material: 15 Mo 3

$K = \overset{v}{\sigma}{}^{T}_{0,2} = 196\ N/mm^2$ (related to T = 300 °C)

$K/s = \sigma_{allowable} = \overset{v}{\sigma}{}^{T}_{0,2}/1,5$ (corresponding to AD procedure)

2.3 Dimensioning

2.3.1 Wall thickness due to inner pressure (AD)

$$s = \frac{D_a \cdot p}{20 \cdot \frac{K}{s} \cdot v + p} + C_1 + C_2 \qquad (1)$$

D_a = 3.300 mm

C_1 = wall thickness fabrication tolerance = 1 mm

C_2 = wall thickness factor due to wear = 1 mm

v = welding factor (assumed to be 0,8)

s = 13,8 mm s_e = 16 mm

2.3.2 Use fraction due to inner pressure and dead weight

a) conservative assumption ($V = 0{,}8$; $C_1 = C_2 = 1$ mm)

Evaluation of dead weight

$$\sigma_{DW} \approx 10 \text{ N/mm}^2$$

The effective primary membrane stress σ_{eff}:

$$\sigma_{eff} = \sigma_{DW} + \sigma_{\text{inner pressure}}$$

$$\sigma_{eff} = \frac{1}{20 \cdot V} \cdot \left(\frac{D_a \cdot p}{S_e - C_1 - C_2} - p\right) + 10 \text{ N/mm}^2$$

$$\sigma_{eff} = 120 \text{ N/mm}^2 < \frac{K}{s} = 130{,}7 \text{ N/mm}^2$$

b) less conservative assumption ($v = 1$; $C_1 = C_2 = 0$ mm)

$$\sigma_{eff} = 87 \text{ N/mm}^2 < \frac{K}{s} = 130{,}7 \text{ N/mm}^2$$

Result

The use fraction due to primary stresses is in between 67 % and 92 %, which is okay.

2.4 Thermal loading

2.4.1 Constructive detail

l_1 = 300 mm

l_2 = 50 mm

h = 17 mm

f = (≙ chap. 2.4.3)

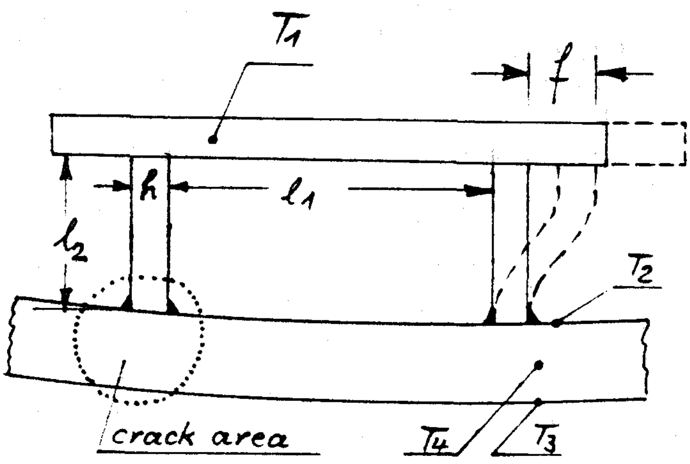


Fig. 2 Baffle plate construction

2.4.2 Loading conditions

Given

- Tube outer surface temperature T_o at sodium inlet for 4 days
- Vessel wall outer temperature T_3 for 4 days

Assumption

- T_1 = Baffle plate temperature corresponding to T_o + 20 °C (as effective sodium inlet temperature) (T_1 and T_3 are given in figure 1a to 1d)

- T_4 = Vessel wall average temperature corresponding to T_3. This related average design temperature for the vessel wall is about 270 °C (see fig. 1a to 1d).

- $\Delta T = T_1 - T_4 = 170$ K for two times per day (given from figure 1a to 1d)

- Failure mode: fatigue damage due to restraint thermal expansion (see dash-lined part in fig. 2)

2.4.3 Fatigue evaluation

a) Bending stress ranges in the vessel wall

$$f = \alpha \cdot \frac{l_1}{2} \cdot \Delta T = 0{,}344 \text{ mm}$$

$$|M_b| = \frac{6EI}{l_2^2} \cdot f \qquad (2)$$

$$\Delta\sigma_b = \frac{M_b}{W_b} = \frac{6E \cdot h}{l_2^2 \cdot 2} \cdot f = \underline{\underline{1.320}} \ / \ \text{N/mm}^2 \ /$$

with $E = 1{,}88 \cdot 10^5$ N/mm² related to 270 °C
$= 1{,}35 \cdot 10^{-5}$ N/mm² related to 400 °C

b) Fatigue damage

Applying design rules of TRD 301:

Stress range by equation (21) of TRD 301 for overelastic case ($\Delta\sigma_b > 2\sigma_{0,2}^T$)

$$2\sigma_a = \frac{\Delta\sigma_b^2}{2 \cdot \sigma_{0,2}^T{}^v} \cdot f_3 \qquad (3)$$

$\overset{v}{\sigma}{}^{T}_{0,2}$ = 214 N/mm² (related to T = 270 °C)

f_3 = surface factor = 1 (perhaps higher due to bad welding condition)

$2\sigma_a$ = 4.070 / N/mm² /

$n_{allowable} \approx 80$ (see figure 3 corresponding to figure 8 of TRD 301)

with $n_{effective} \approx$ 2 times 60 days = 120

fatigue damage $u = \frac{120}{80} = 1,5 > 1$

2.4.4 Additional uncertainties

- not considered influence of relatively high mean stress (due to dead weight and inner pressure)
- multiaxial stress state
- welding influence
- neglected loading due to temperature gradient across vessel wall (T_2 - T_3)
- higher design temperature than 270 °C at vessel inner surface ($T_2 > T_3$)

3 New design

3.1 Mechanical loading and dimensioning

see chapter 1.1 to 1.3

3.2 Thermal loading

a) Conservative assumption

No mixing effect is considered; no damping of the sodium temperature is considered: $\Delta T = 170$ K

Design temperature (due to equation (1) of TRD 301)

$$\vartheta^* = \check{\vartheta} + 0,75\ (\hat{\vartheta} - \check{\vartheta})$$

with $\check{\vartheta} = 240$ °C

$\hat{\vartheta} = 410$ °C

$$\vartheta^* = 370\ °C \rightarrow \check{\sigma}_{0,2/\vartheta^*} = 173\ /\ N/mm^2\ /$$

$$\Delta\sigma = \frac{E\ .\alpha}{1-\nu}\ .\Delta T = \frac{1,72.10^5.1,33.10^{-5}}{0,7}\ .170 = 555\ /N/mm^2/$$

$$2\sigma_a = \frac{555\ .\ 555}{2\ .\ 173} = \underline{\underline{890\ N/mm^2}}$$

$$\underline{\underline{n_{zul} \approx 3.200}}$$

b) Considering of mixing effect

Taking into account mixing effects leading to reduced temperature difference ΔT on the vessel wall, the corresponding results are given in table 1 and figure 4 showing very clearly the influence on allowable number of events.

3.3 Results and conclusions

- Apart from the certain situation of the baffle plate construction which has been investigated in chapter 2, the cold storage vessel cannot be failed due to thermal transients. This result is in accordance with / 1 /.

- Mixing effect has an important influence on increasing number of allowable transient events.

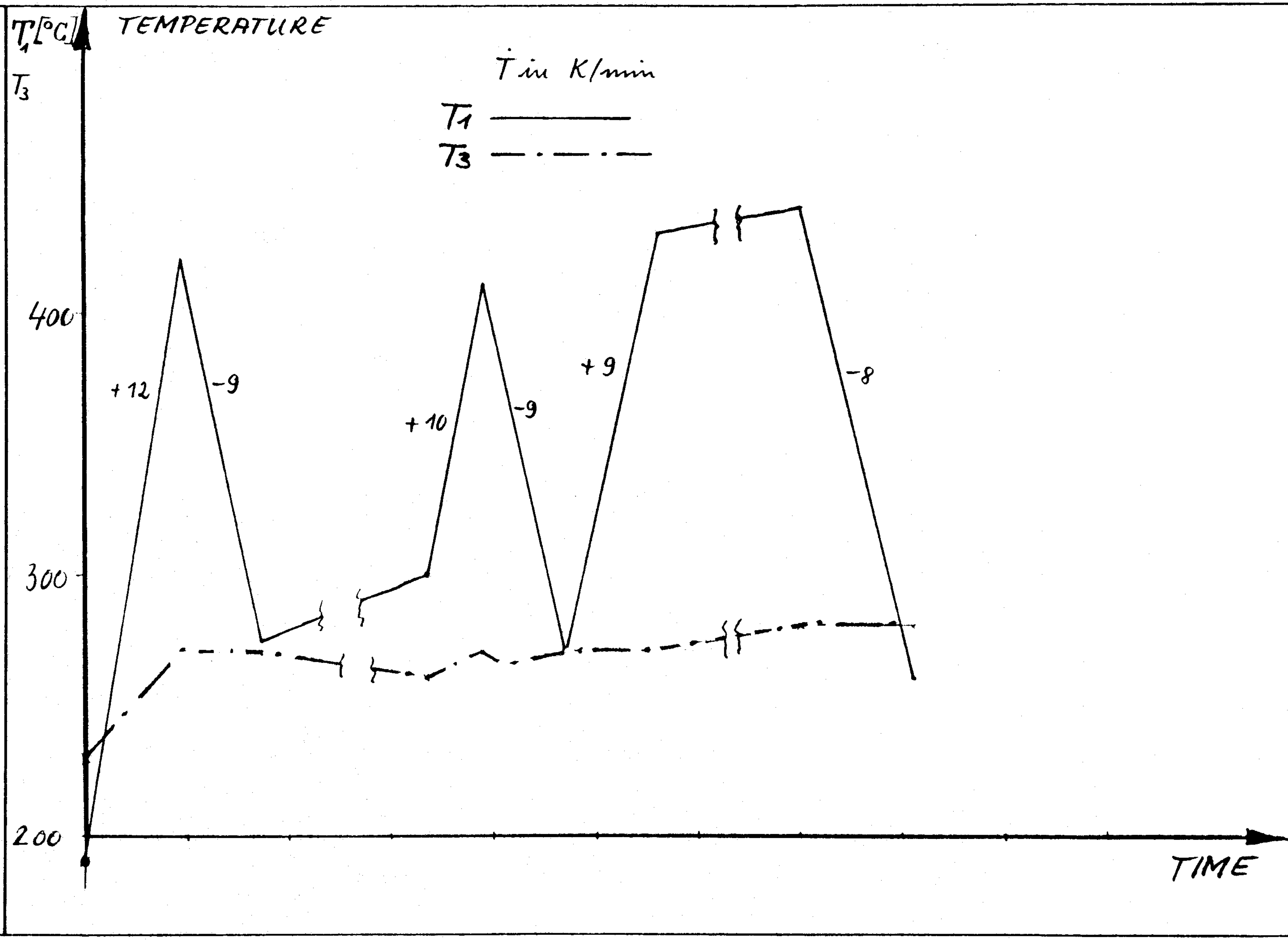
- The new construction exhibits a lot of advantageous aspects which have not been considered in the calculations, expecting evident improvements of thermal transient conditions. These aspects are:

  . Mixing tee construction
  . Hot sodium inlet far from vessel wall (damping effect)
  . No geometrical discontinuities in the vessel wall

/ 1 / J. G. Martin
"Thermal Shock as a possible cause of sodium leaks"
DFVLR-report Nr. R-84/82 JM3231 from 31.10.82

Mixing effect in % ΔT	ΔT / °C /	ϑ^* / °C /	$\Delta\sigma$ / N/mm² /	$2\sigma_a$ N/mm²	$n_{allowable}$
0	170	370	555	890	3.200
10	153	355	518	762	5.100
30	119	330	405	446	50.000
50	85	304	289	289	$>10^6$

Table 1: Influence of assumed temperature mixing on allowable number of cycles



LOADING HISTOGRAMME (22.9.82)

Fig. 1a

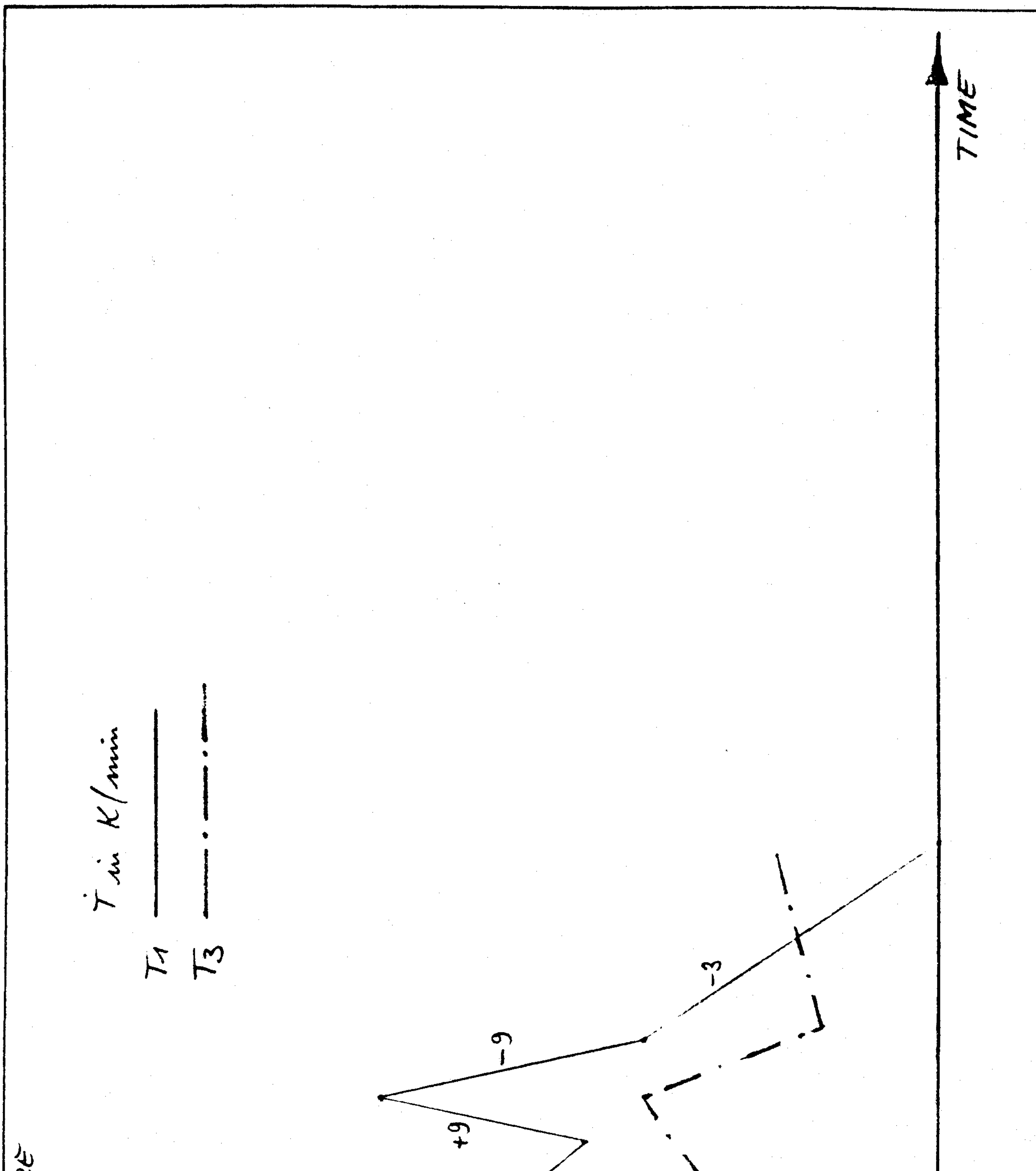


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Fig. 1b

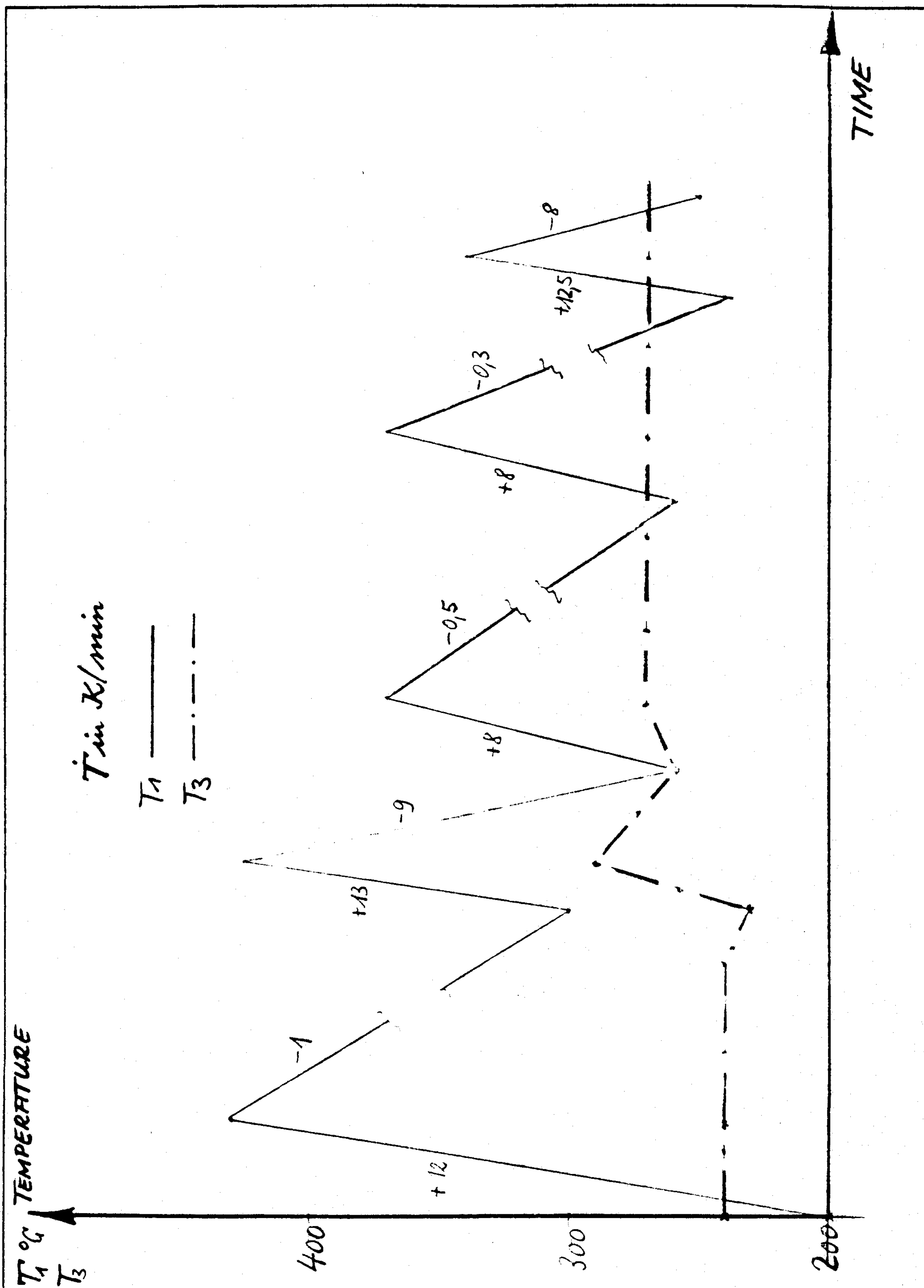

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Fig. 1c

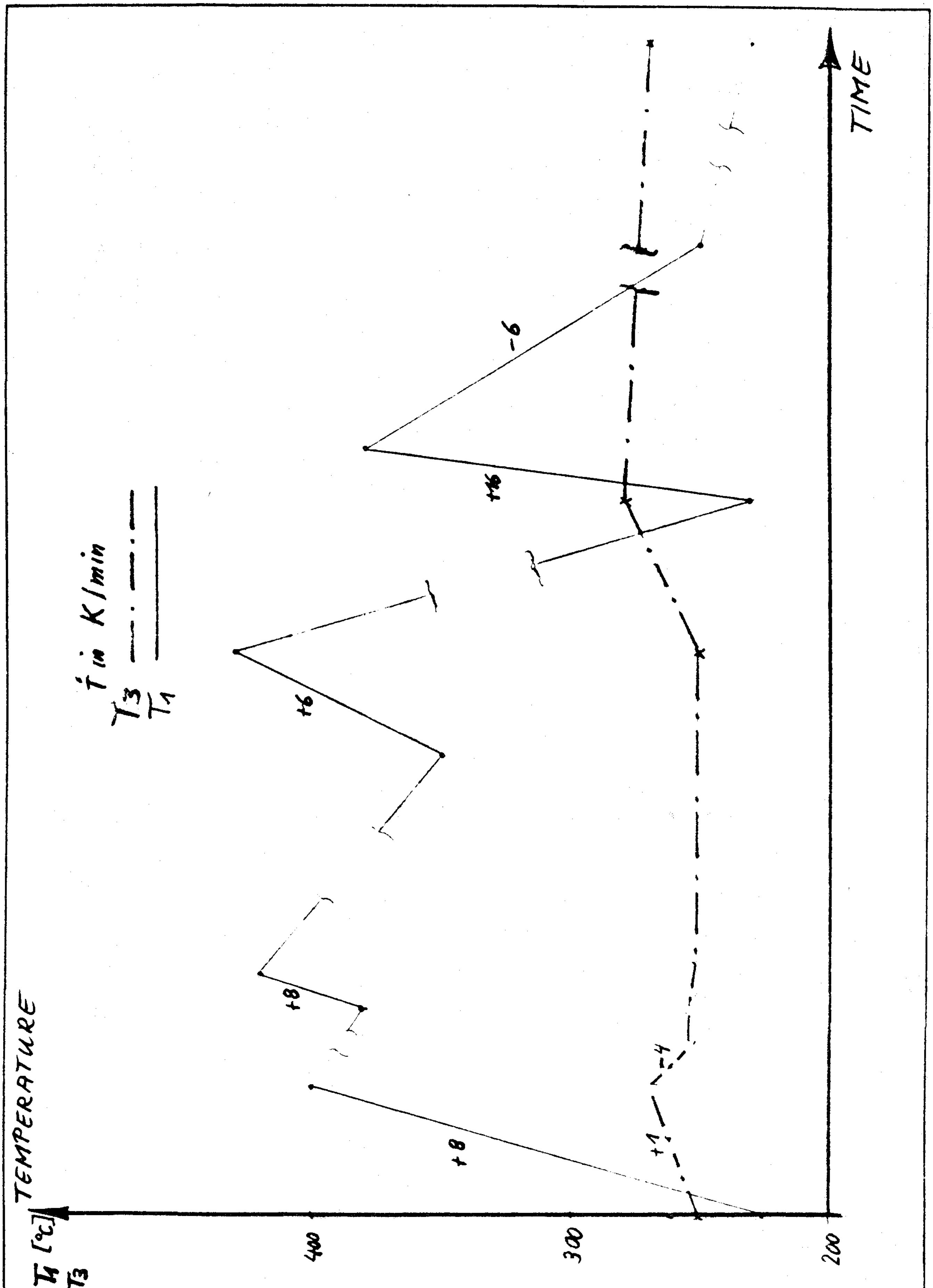

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Fig. 1d

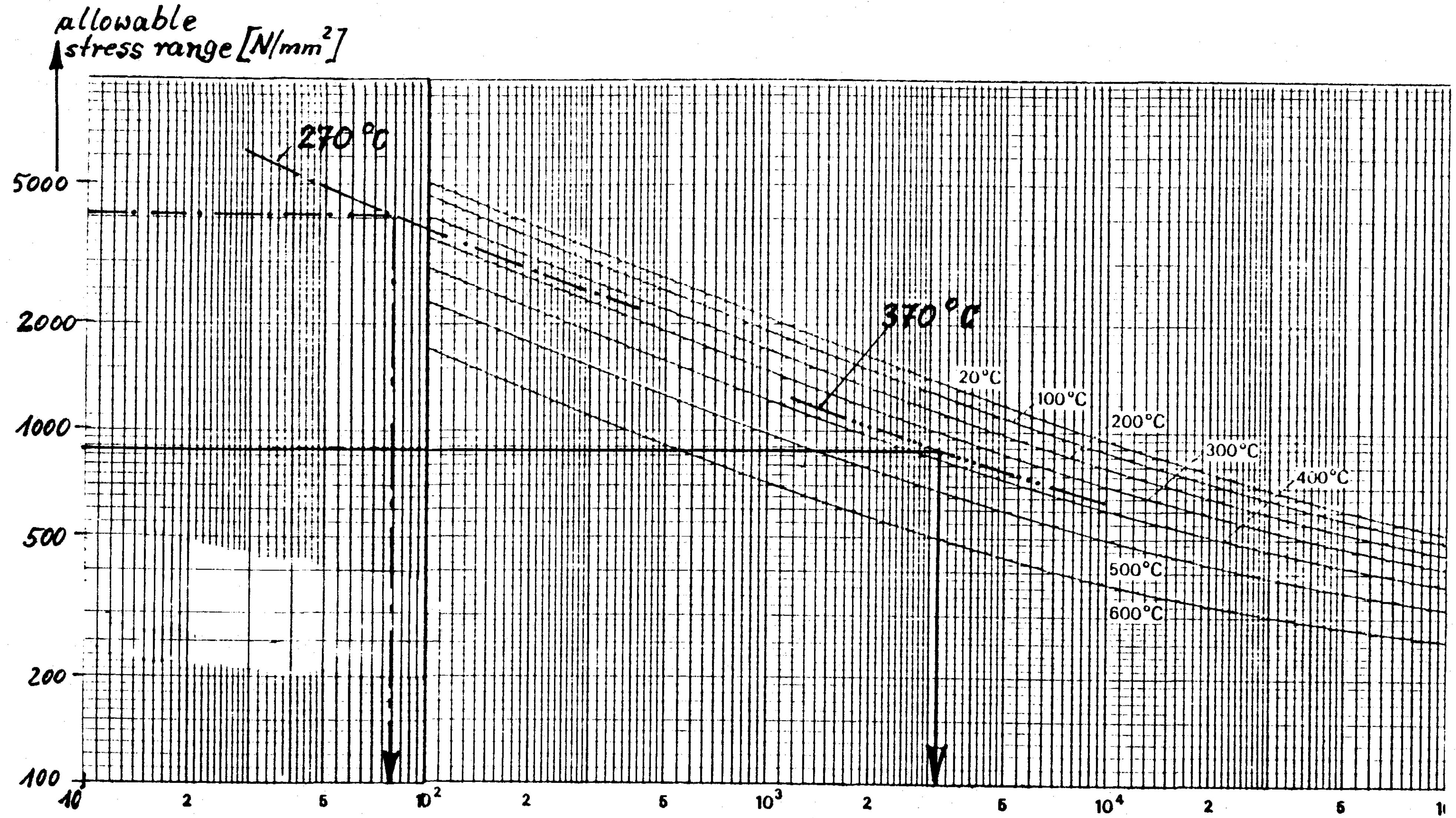

Fig. 3: Evaluation of allowable cycles at paffle plate area (—.—.— old design) and undisturbed vessel wall (—— new design)

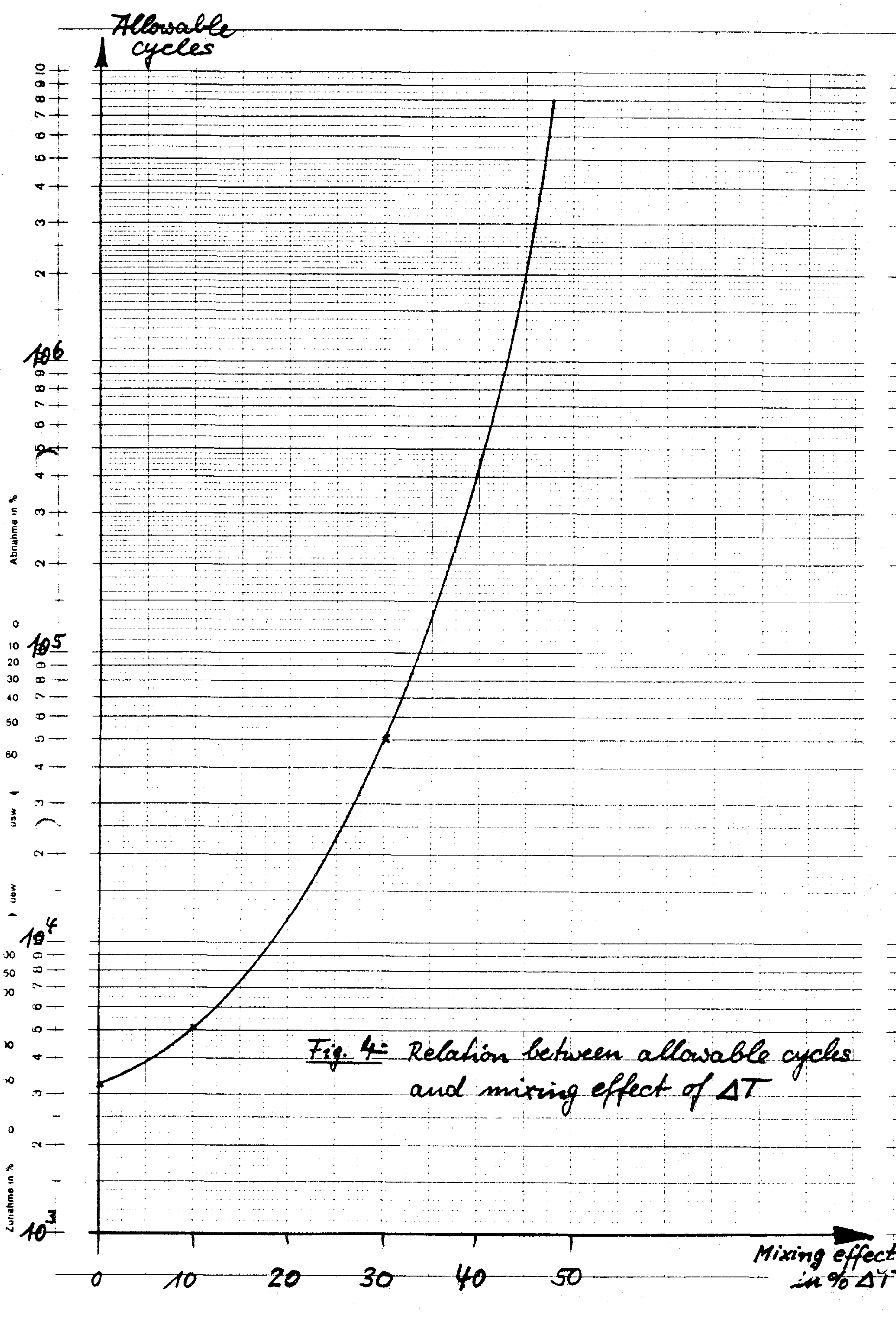

Fig. 4: Relation between allowable cycles and mixing effect of ΔT

IEA - SSPS PROJECT CRS

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CHAPTER I.IV

Inspection and Possible Modification of the Hot Storage Vessel LK02 BB01

Prepared by: INTERATOM
TVS No.:
Date: 82-11-25
Revision:
Approved by:

1192/10 79/2 (SSPS 009/4000/B)

Contents

1 Inspection Program for the Hot Storage Vessel LKO2 BBO1

Due to the similar design of the hot storage vessel, there are also two baffle plates in the lower part of the vessel under the down-comer pipes.

Even if the main design details like material (austenitic steel), wall thickness (20 mm) as well as the operational conditions (530 $^{\circ}C$), not cyclic temperature change are quite different, a basic non-destructive inspection program is recommended which would include the following steps:

- dismantling of the thermal insulation in the region of the two baffle plates (between vessel supports)
- visual inspection of the free surface
- ultrasonic inspection of the two baffle plate areas to record the basic conditions; this inspection is highly complicated but in general possible if special inspection techniques (SEL) are applied and performed by experienced quality control specialists.

Before this procedure can be initiated a common agreement with respect to the UT-technique as well as the interpretation of results must be reached under the involved experts.

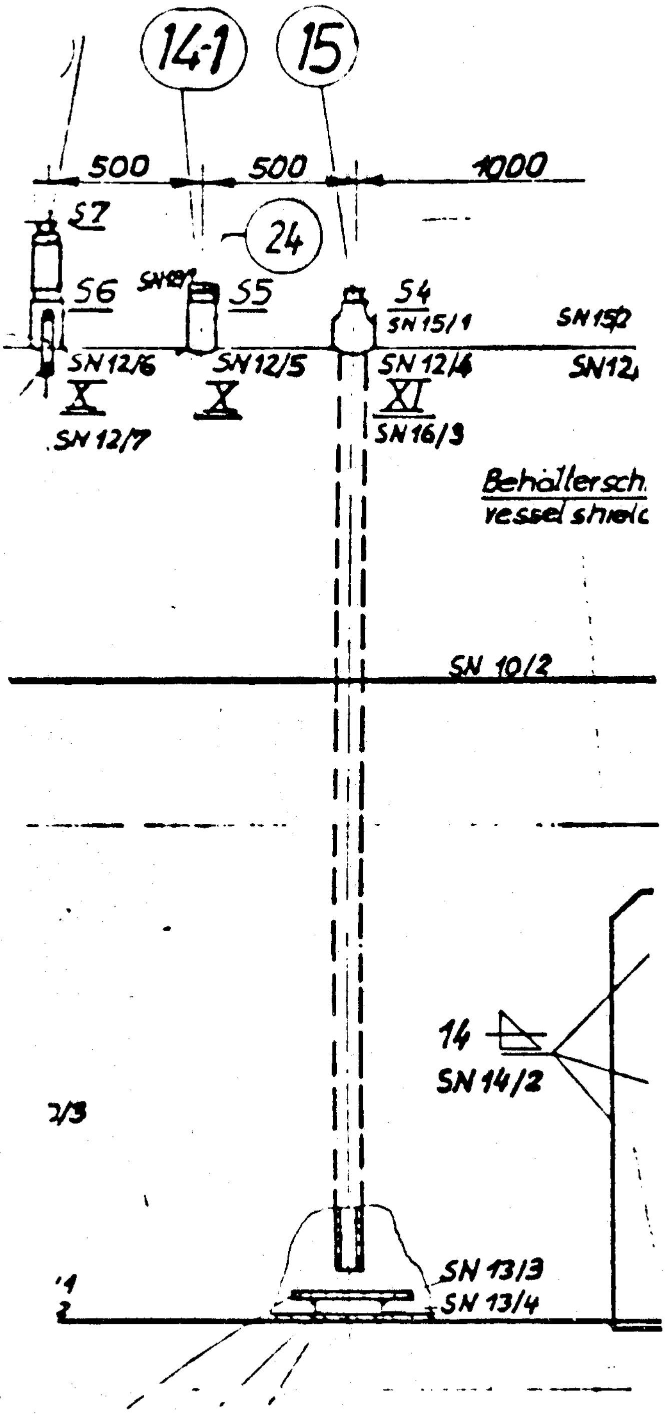
The procedure will need approx. 2 weeks after emptying and cooling down of the hot storage vessel and can be started after finalization of the repair of the cold storage vessel.

2 Possible Modification of the Hot Storage Vessel

In view of the experience gained during the failure investigation of the cold storage vessel it turned out that a relatively simple modification of the down-comer pipes should be performed which would improve the operational conditions of the hot storage vessel remarkably. The attached figure shows the proposed modification of the lower part of the down-comer pipe of joint no. S4 (reflow from receiver outlet) which comprises a closing of the tube end and drilling of sufficient number of spray bores. The installation of this modification can be performed as follows:

- dismantling of the thermal insulation of the down-comer pipe outside the vessel at the connection weld seam
- cutting of the outer weld seam of the thermal sleeve nozzle
- pulling out vertically the down-comer pipe considering the necessary safety measures, provisionally closing of nozzle
- cleaning and modification of the lower part of the pipe
- inserting the modified pipe and welding of the nozzle seam according to specification
- reinstallation of thermal insulation.

Before this procedure can start an agreement must be reached with respect to boundary conditions and single work steps.



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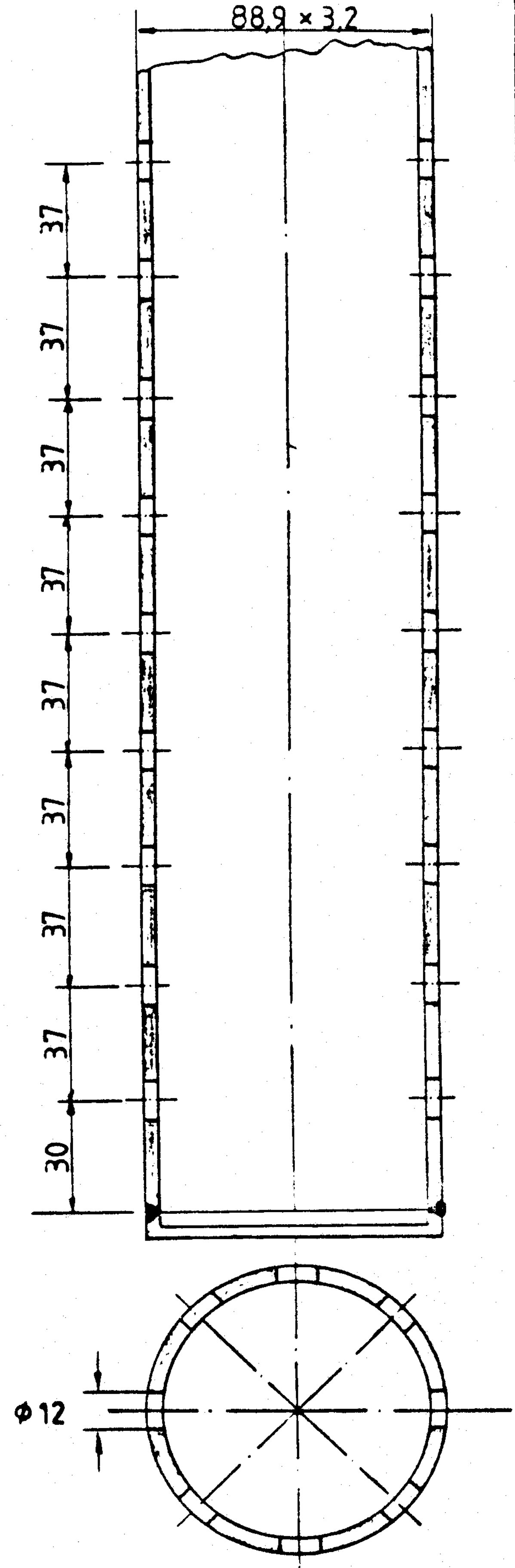


INTERATOM
INTERNATIONALE ATOMREAKTORBAU GMBH

Modification Hot Storage
Inlet Tube Nozzle No. S4

CHAPTER II

POWER CONVERSION SYSTEM

Chapter II.I

Evaluation and Possible Modification of the Power Conversion System

Prepared by: INTERATOM

TVS-No.: 129646

Date: 82-11-25

Revision: 0

Approved by:

Contents

1 Power Conversion System Evaluations

After detailed evaluation with respect to the CRS Power conversion system including several discussions with Operating Agent and Spilling Comp. the following main results can be given concerning

- installation of new turbine systems
- preserving of Spilling steam motor system

as well as the conclusions from the side of INTERATOM.

1.1 New Turbine Solutions

As a consequence of the decision of the EC-meeting held on June 29th, 1982 to modify the PCS INTERATOM started an inquiry procedure for a new PCS-system with a turbine-alternator set beginning August 1982 in agreement and on behalf of the Operating Agent.

This inquiry was extended to 15 different companies in 6 different countries (involved in the project).

The evaluation of the proposals resulted in the following:

- one offer including the complete engineering, supply of auxiliary equipment and one turbine version, installation and commissioning

- one offer including the complete engineering, supply of auxiliary equipment and four different turbine versions, installations and commissioning

- one offer for the supply of a turbine only

The conclusion of these a. m. proposals was:

- the cost figures of all offered turbine versions have overpassed the expected funding limits

- all the different offered turbine versions would have a much lower gross electrical output than that of the existing steam motor (worse efficiency)

- the evaluation of the different time schedules has shown a delivery time including installation of appr. 10 - 12 months

On the basis of a prelimiary unwritten offer for a used turbine the installation of such a used turbine (there is one available in USA, approx. 30 years old) have also been considered.

For the following reasons this solution is not recommendable:

- the limited availability of spare parts in the future
- the impossibility of warranties
- the relative high costs for turbine and installation, which is in no reasonable relation to the eventual advantage of such a version. Besides this it is not to be expected that the required electrical gross output can be realized.

In addition the fact must be seen that the installation of a partially modified system and the connection to the exisiting one will create certain risks during commissioning and start-up of the PCS which could influence the operational availability.

1.2 Preservation of Spilling Steam System

Because of the realized functional tests of the PCS system up to the end of 1981 and - after some modification - the additional operational time between July and Sept. 82 the obtained data show, that remarkable improvments of the steam motor have been reached with respect to efficiency and reliability of the system. The fact was, that during the first test period up to the end of 1981 the full load conditions with the steam motor could not be realized (max. output appr. 500 kW). After some specified modifications before and during the operational time between July and Sept. 82 all expectations regarding the electrical net output were nearly fulfilled (max. output appr. 585 kW).

Even that there have been some damages at the steam motor during the last a. m. operational period an impressive ability to repair these breakdowns in a very short time could be demonstrated thus reducing the plant's outages.

Nevertheless since the last repair (Aug. 8 - 9, valve rod breakage No. 3 cylinder) the steam motor has been run under full automatic control whenever sufficient energy was available which has shown that the availability of the steam motor was improved remarkably.

Date	max. gross output kW_e	Gross energy kWh
30.07.82	525	1.290
31.07.82	520	1.105
03.08.82	575	1.292
04.08.82	575	1.062
11.08.82	580	1.391
15.08.82	600	1.183
22.08.82	600	898
06.09.82	600	1.375

This a. m. column, in which only the main steps are shown is self explanatory. Up to Sept. 25th, a total of 22.640 kWh electrical energy was produced into the grid.

Nevertheless it should be mentionioned again that the operation of the PCS is penalized by the normally unavoidable short daily operational times and in addition by many interruptions due to e.g. bad weather conditions and failures of other subsystems of the plant.

A highly developed and complicated automatic system (high temperature and pressure conditions) such as the installed PCS has suffered much more from the a.m. interrupting effects than a more simple manually operated low pressure system especially during the first commissioning times and a lot of activities have been spent to overcome this specific former sensitivity.

1.3 Conclusions and Offered Solutions

Considering the results of the a.m. evaluations (see para. 1.1 and 1.2) the modifications of the existing PCS by installation of a new (or used) turbine seems not to be recommendable.

On the other hand there are the improvements made with the existing PCS with repect to efficiency and reliability which indicate the possibility of sufficient operation in the following period of time.

Nevertheless it is to be accepted that such a complicated system does need more efforts regarding maintenance than more simple circuits which is a clear result of past experience.

To avoid any additional costs resulting from these extended maintenance necessities INTERATOM offers the maintenance and evtl. repair work of the complete PCS-system up to the end of 1983 free of charge (without wear materials and operating media) including all during this period evtl. neccessary steam motor spare parts.

2 Additional System Modifications

As an important part of the evaluation procedure several system improving possibilities have been considered.

As the most interesting ones the following subjects have been investigated in detail to prove their feasibility:

- Installation of a fossil fired Na-heater and
- possible connection of CRS- and DCS-PCS.

The next paragraphs will show that only the first solution is of such a value that it should be realized.

2.1 Installation of a Fossil Fired Na-Heater

From the beginning of the SSPS project one of the basic requirements was the demonstration of a highly complexe and multi-purpose solar power plant like e. g.

- demonstration of complete energy conversion by installation of a PCS including generator

- demonstation of either grid connection or supply to an insulated consumer by installation of an electrical substitute load

- demonstration of hybrid (solar/fossil) operation by installation of a secondary (fossil fired) energy source.

Due to financial reasons the third tasks never has been realized.

The first operational year of the CRS plant has indicated that in special the unexpected but unavoidable bad weather has created many problems during commissioning and operation of the plant. As a most important fact the bad relation of the start-up time to the operational time of the plant's subsystems must be seen.

There seems to be one possibility to overcome this handicap in connection with the solution to improve the power conversion part of the plant.

The fossil fired (oil or gas) sodium heater of one of INTERATOM's Na-test facilities with a capacity of appr. 5 MW_{th} could be available to be removed from the test-facility and transported to Almería and installed as a part of the CRS plant.

At present a detailed inspection of this heater is being performed to prove the actual condition which is a presupposition for any further application.

The description of this component is shown in the chapter II.II.II of this document.

First financial calculations have yielded the following costs:

- Na-heater completely inspected and renovated as necessary (e. g. new oil furnace), dismantled from test facility and transported to Almería

  appr. <u>630 TDM</u> (incl. 500 TDM for Na-heater)

- Installation of Na-heater and connection with the system

  appr. <u>350 TDM</u> (incl. manpower and hardware)

Considering the attractive improvement of the CRS plant like

- demonstration of a hybrid solar power plant system (most flexible demonstration plant world wide)

- compensation of non-radiation operational periods of the plant being able to produce full electric output

- extension of the operatinal time of the PCS to improve relation between start-up and steady-state operation

the costs for the installation of this Na-heater should be funded by the SSPS project while the renovated heater would be delivered free of charge by INTERATOM. Further detailed discussions should clarify these possibilities after the basic desicion has been made.

The complete installation of the Na-heater is expected to need not more than 3 - 4 months.

2.2 Possible Connection of CRS- and DCS-PCS

The connection of the CRS with the DCS Power Conversion system in a one-way version has been investigated in detail.

The advantage to overcome non-operational periods of the existing steam motor due to e. g. inspection, maintenance, repair by using the produced steam to drive the DCS turbine/generator set can only be realized by a non-completely sufficient technical solution.

As indicated in detail in the following chapter II.II.I this connection is possible in principal but shows some remaining problems and disadvantages:

- the realized gross electrical output is not more than appr. 350 kW_e

- the different control systems of the existing PCS which have to be connected might create some further operational problems

- the unnormal long exhaust steam connection pipe needs extremely precise preheating and draining possibilities

- necessary installation time of appr. 4 - 6 months

In comparison of the poor result of the energy conversions with the necessary efforts for realisation this modification of the system is not recommendable at all.

CHAPTER II.II

Detailed Technical Description of Possible Modification

Chapter II.II.I
Connection of CRS and DCS Power Conversion Systems

Prepared by: INTERATOM
TVS-No.: 129646
Date: 82-11-25
Revision: 0
Approved by:

Contents

1 Description of Process

In case of an unforeseen steam motor failure of the CRS-plant the live steam of this plant shall be led to the turbine of the DCS plant. The pressure and temperature of this steam have to be reduced because the inlet conditions of the turbine are much lower. At the first glance it seems to be obvious to use the existing steam cooler of the CRS plant but this solution is not possible without changing the whole control system. Therefore it is easier to choose a separate reduction valve and separate steam cooler for reducing the steam pressure from 100 bar to 25 bar and the temperature from 500 °C to 280 °C.

Behind this cooler there are two reduction lines for feedwater preheating. This preheating with live steam is necessary because the pressure of the turbine extraction steam is too low. The pressure of the extraction steam is 3.4 bar but for the 2. preheating stage we need 15 bar. The extraction steam of the turbine will be used for preheating the condensate and the feedwater tank.

Some problems are to be expected with the exhaust steam of the turbine. One possibility is to use the condenser system of the DCS plant and to pump the condensate to the feedwater tank of the CRS plant. In this case the condenser system of the CRS plant (in special the evaporating system) is not prepared for a failure of the turbine. When turbine operation is stopped steam production can not be stopped without damage of the sodium-heated steam generator. Therefore the pressure relief pipe and the condenser system of the CRS plant have to come in operation.

For this reason it is considered to lead the exhaust steam of the turbine to the condenser system of the CRS plant. The designed volume flow of the CRS system is four times smaller than that of the DCS plant. Therefore the exhaust pressure of the turbine has to be increased from 0.07 bar to about 0.3 bar. Stal-level - as the supplier of the turbine - has been asked for the consequences of this pressure increase and has confirmed the possibility.

The changes of data and conditions of the described combination of the CRS and DCS plant are calculated in the next chapter.

2 Process Calculation

2.1 Main Design Data

2.1.1 CRS Plant

Inlet steam:

$p = 100$ bar
$t = 500$ °C
$\dot{m} = 3.105$ kg/h
$h = 3.375$ kJ/kg

Extraction steam

Condensate preheating
p = 1,4 bar
t = 109 °C
$\dot{m}$ = 279 kg/h

1. Feedwater preheating
p = 5.5 bar
t = 175 °C
$\dot{m}$ = 271 kg/h

2. Feedwater preheating
p = 15 bar
t = 260 °C
$\dot{m}$ = 276 kg/h

Exhaust steam

p = 0.3 bar
t = 69 °C
$\dot{m}$ = 2.279 kg/h
h = 2.475 kJ/kg

2.1.2 DCS Plant

Inlet steam: p = 25 bar
t = 283 °C
$\dot{m}$ = 3.767 kg/h
h = 2.968 kJ/kg

Extraction steam

$p = 3.4$ bar
$\dot{m} = 523$ kg/h
$h = 2.705$ kJ/kg

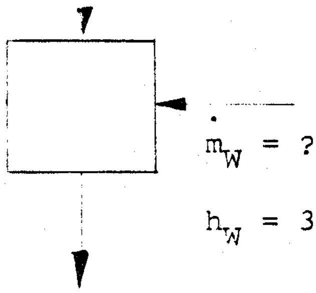
Exhaust steam

$p = 0.07$ bar
$\dot{m} = 3.126$ kg/h
$h = 2.277$ kJ/kg

2.2 Steam from CRS to DCS

2.2.1 Steam Cooler

$\dot{m}_{CRS} = 3.105$ kg/h
$h = 3.375$ kJ/kg



$\dot{m}_W = ?$

$h_W = 340$

$\dot{m}_2 = ?$
$h_2 = 2.968$

$$\dot{m}_2 = \dot{m}_{CRS} + \dot{m}_W$$
$$\dot{m}_{CRS} \cdot h_{CRS} + \dot{m}_W \cdot h_W = \dot{m}_2 \cdot h_2$$

$$\dot{m}_W = \dot{m}_{CRS} \frac{h_{CRS} - h_2}{h_2 - h_W}$$

$\dot{m}_W = 380$ kg/h
$\dot{m}_2 = 3.585$ kg/h

For Feedwater preheating we take the old flow (s. Flow sheet CRS Plant)

1. Feedwater Preheater $\dot{m}_{1PH} = 271$ kg/h
2. Feedwater Preheater $\dot{m}_{2PH} = 2,76$ kg/h

The superheating energy of the new steam is higher than the old one, but there is only a small change in the total enthalpy difference

<u>Turbine Inlet Steam from CRS</u>

p_T = 25 bar
t_T = 283 °C

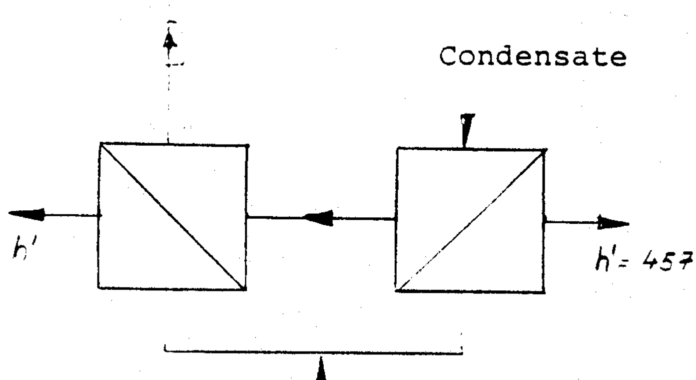
$m_T = m_2 - m_{1PH} - m_{2PH}$ = 3.038 kg/h

$$\frac{mT}{m_{Design}} = \frac{3.038}{3.767} = 0{,}81$$

The steam flow from CRS will be only 81 % of the design flow.

2.2.2 Extraction Steam from Turbine for preheating Condensate and Feedwater Tank

Assumption: The Condensate conditions of the CRS Plant will be reached.



m = 3.105 kg/h
p = 1,2
t = 49 °C
h = 205 kJ/kg

p = 1,4 bar
h = 2.705
Extraction steam

m_{EX} (2.705 - 457) = 3.105 (440 - 205)

$\underline{m_{EX} = 325\ kg/h}$

$$\frac{\dot{m}_{EX}}{\dot{m}_{EXDes}} = \frac{325}{523} = 0.62$$

Only 62 % of the designed extraction steam will be needed for condensate preheating. The pressure of extraction steam must be decreased from 3.4 to 1.4 bar.

2.3 Check of the Turbine Outlet Conditions,

when the exhaust steam is led to the condenser system of the CRS Plant

Comparison of the outlet area

$$A = \frac{\dot{m}\ V}{W} \qquad V = V' + X\ (V'' - V')$$

Assumption $W_{Tex} = W_{CRS}$ (same velocity)

T_{ex} ≙ Turbine exhaust

CRS = designed CRS data

$$\frac{A_{Tex}}{A_{CRS}} = \frac{m_{Tex} \cdot V_{Tex}}{m_{CRS} \cdot V_{CRS}}$$

New turbine exhaust flow

m_{Tex} = 3.038 - 325 = 2.713 kg/h

1. Assumption p_{Tex} = 0.07 bar

$$V_{Tex} = 0.001 + 0.8775\ (20.53 - 0.001) = 18.015\ m^3/kg$$

$$V_{CRS} = 0.001 + 0.94\ (5.229 - 0.001) = 4.914\ m^3/kg$$

$$\frac{A_{TEX}}{A_{CRS}} = \frac{2.713\ .\ 18.015}{2.279\ .\ 4.914} = 4.36$$

For the designed turbine exhaust pressure of p = 0.07 bar the cross section of the CRS-condenser system is too small. The turbine exhaust pressure has to be increased up to about 0.3 bar.

The problems which can arise by the long exhaust pipe are not analysed in detail. The power losses which will be caused by exhaust pressure increase are calculated in the following section.

2.4 Power Losses of the Turbine

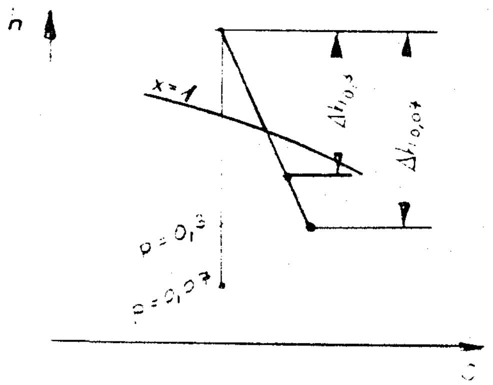
when operating with CRS steam

When operating with CRS steam there will be 3 main factors of power decrease

1. flowrate will be lower
2. enthalpy-difference will decrease
3. turbine efficiency will be smaller

$$P \sim \dot{m} \cdot \Delta h \cdot \eta_T$$

Neglecting the decrease of η we can calculate the new Δh when increasing the outlet pressure from 0.07 to 0.3 bar.



$\Delta h_{0.07} = 2.968 - 2.277$
$= 691$ kJ/kg

$\Delta h_{0.3} = 2.968 - 2.420 = 548$

$$\frac{P}{P_{Des}} = \frac{\dot{m}}{\dot{m}_{Des}} \cdot \frac{\Delta h}{\Delta h_{Des}}$$

$$= 0.81 \; \frac{548}{691} = 0.81 \; . \; 0.79 = 0.64$$

Without regard of efficiency losses the power of the turbine will decrease to 64 % of the design value

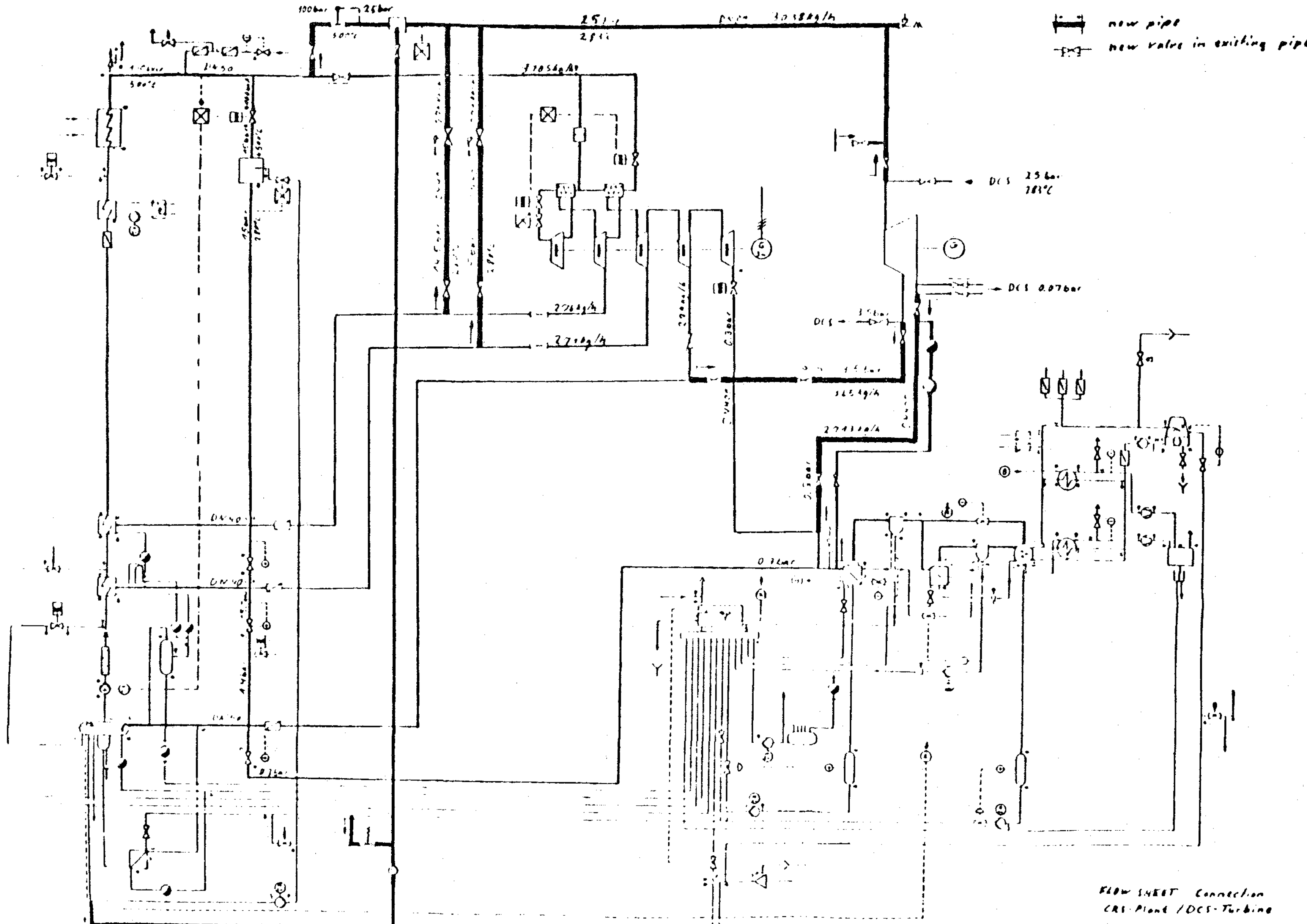
$P = 0.64 \; . \; P_{Des} = 0.64 \; . \; 577 = 370$ kW

Stal Laval has made calculations taking into consideration the efficiency losses of the turbine. They found out a generator output of P = 340 kW. This is only 59 % of the reference power.

Additional to this large power loss, problems with the control systems cannot be excluded when combining both systems CRS and DCS and operating them with load variations.

3 Flow Diagram

The attached flow diagram shows the possible new process as a functional connection of the power conversion systems of the CRS- and the DCS-plant. The indicated process data refer to the before mentioned full load conditions.



IEA – SSPS PROJECT CRS

INTERATOM

IL 11 10 79 2 (SSPS/002/4000)

SSPS	IEA – SSPS PROJECT CRS	INTERATOM INTERNATIONALE ATOMREAKTORBAU GMBH

Chapter II.II.II
Description of a Fossil Fired Sodium Heater

Prepared by: INTERATOM
TVS-No.: 129646
Date: 82-11-25
Revision: 0
Approved by:

Contents

1 Description of Process

The task of the sodium heater is to produce independently from the solar insolation hot sodium of 530 °C into the hot storage vessel. The capacity is designed for 2,3 MW_{th} ≙ 100 % expected solar power at equinox noon.

As can be seen in the attached flow diagram, the sodium heater should be installed between the cold- and hot storage vessel (in parallel to the receiver). During operation the sodium is coming from the cold storage vessel via sodium pump No-1 with 275 °C, passes the sodium heater, is heated up to 530 °C and flows to the hot storage vessel.

The degassing of the sodium heater is connected with the receiver overflow pipe. The sodium drainage of the heater can be realized (after the heating procedure) into the main receiver sodium pipe, so, that in each case the system dumping to the storage tanks is possible.

The oil of the vessel burner could be taken from the existing oil storage tank of the auxiliary diesel generators (has to be checked).

The sodium heater with an altitude of appr. 17.0 m should be installed outside the north-east corner of the sodium hall (beside the steam generator room).

2 Description of the Sodium Heater

The sodium heater is installed at the INTERATOM test facilities and was many years in operation. The general construction is like a combined radiant and convection boiler.

The sodium heater entails an oil-fired vessel where fluid sodium is heated up from 275 °C to 530 °C. The firing chamber (radiant heating portion), tube panels, air preheater and the stack are vertically arranged, one above the other. The burner is located in the midst of the floor support. The combustion air, preheated to 290 °C is blasted from below into the firing chamber via air vanes (can also be delivered without air preheaters).

The radiant heating portion of the firing chamber has an inner diameter of 2 m and a height of 6 m. The wall tubing of this boiler portion are spiral wounded. The combustion gas flowing to the end of the radiant heating portion (inlet of the tube bundles) is cooled down to 1010 °C.

The sodium boiler at INTERATOM was installed during 1965/66. Since its erection it has had over 30.000 operating hours without any mentionable disturabances. The boiler is remaining available for varions test assignments for reactor component heat transfer.

Main Data of Sodium Heater

(In the following are the data of the existing sodium heater listed, which could be lowered for the using in the CRS-power plant.)

Boiler

Maximum power	$4{,}3 \times 10^6$ kcal/h
Exhaust losses	17 %
Radiation losses	2,5 %
Efficiency	80,5 %

Sodium

Max. throughput	120 t/h
Inlet temperature	300 °C
Outlet temperature	560 °C
(can be changed between 275/530 °C)	
Pressure losses	1,1 bar
Operating pressure	6,0-12,0 bar
Calculated maximum temperature	600 °C

Air and Exhaust

Combustion air volume	13,35 Nm^3/kg
Combustion air volume	7350 Nm^3/h
Minimum stack gas volume	11,42 Nm^3/kg
Stack gas volume	7740 Nm^3/h
CO_2 max.	15,5 %
O_2	4,5 %
CO_2 usual	12,3 %

Fresh air temperature	20 °C
Hot air temperature	290 °C
Stack gas temperature (end of fire chamber)	1010 °C
Stack gas temperature (before air preheater)	595 °C
Exhaust gas temperature	370 °C

Fuel Oil

light fuel oil
(has to be clarified at the site)

Fresh Air Fan

Air inlet temperature	20 - 150 °C
Air volume capacity	2,1 - 2,5 m^3/s
Static air pressure	418 - 274 mmWS
Fan capacity	8,7 - 10,7 kW
Revolution	1450 Rpm
Motor capacity	15 kW

Measurements, Heating Surfaces

Radiation heating surface (wall tubes)	110 m^2
Bundle heating surface	135 m^2
Air preheater heating surface	123 m^2
Wall tubes around the bundle	56 m^2

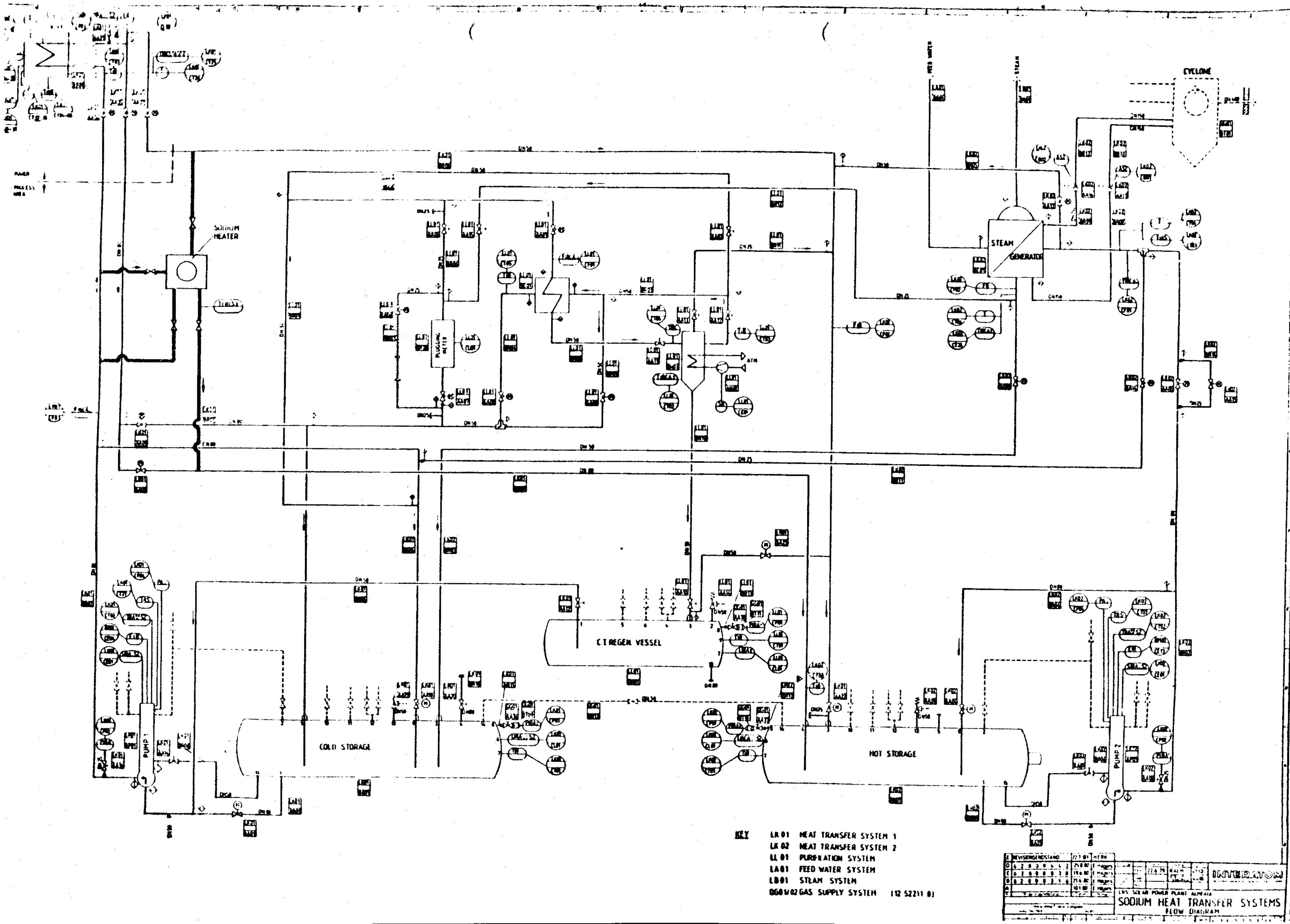
Tube measurements

-	wall tubes	26,8 x 2,9 mm
-	bundle tubes	33,7 x 2,9 mm
-	down pipes	44,5 x 3,6 mm
-	header	133 x 12 mm
-	inlet and outlet	38,9 x 5,0 mm
-	air preheater	51 x 2,9 mm

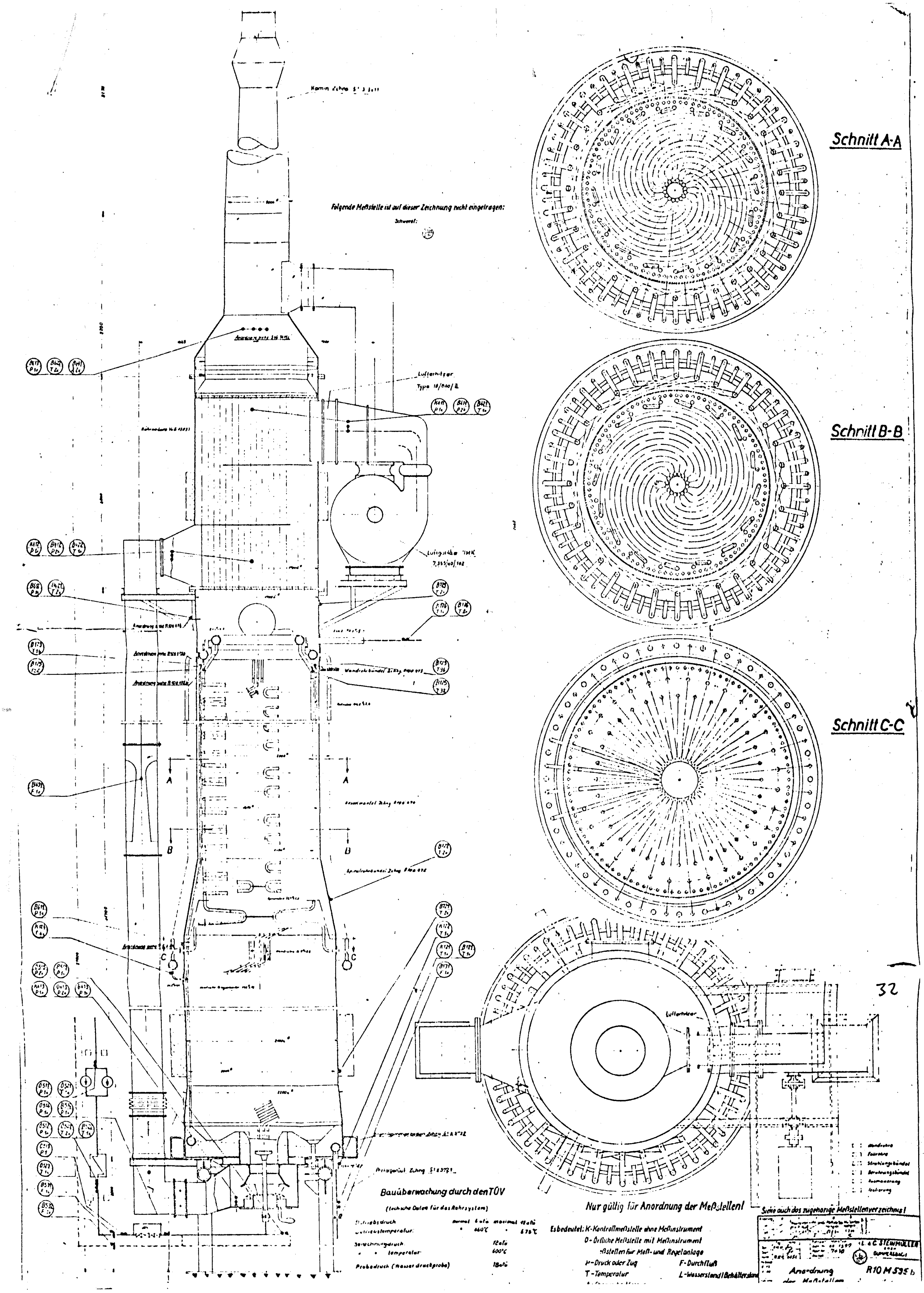
Number of parallel	- wall tubes	96
	- bundle tubes	32
	- down pipes	32
Length of	- wall tubes	20,4 m
	- bundle tubes	40,7 m
	- down pipes	7,06 m

General Data

Weight of the sodium heater (without stack and thermal insulation)	appr. 20 tons
Sodium filling volume of the heater	appr. 10 tons



SODIUM HEATER
FEED WATER
STEAM
CYCLONE
STEAM GENERATOR
PLUGGING METER
C.T. REGEN. VESSEL
COLD STORAGE
HOT STORAGE
PUMP 1
PUMP 2
KEY
LK 01 HEAT TRANSFER SYSTEM 1
LK 02 HEAT TRANSFER SYSTEM 2
LL 01 PURIFICATION SYSTEM
LA 01 FEED WATER SYSTEM
LB 01 STEAM SYSTEM
QG01/02 GAS SUPPLY SYSTEM
INTERATOM
SODIUM HEAT TRANSFER SYSTEMS
FLOW DIAGRAM


32
Schnitt A-A
Schnitt B-B
Schnitt C-C
Folgende Meßstelle ist auf dieser Zeichnung nicht eingetragen:
Lufterhitzer
Type 18/800/8
Bauüberwachung durch den TÜV
(technische Daten für das Rohrsystem)
normal 6 atü maximal 11 atü
660°C 675°C
12 atü
600°C
Probedruck (Wasserdruckprobe) 18 atü
Nur gültig für Anordnung der Meßstellen!
Es bedeutet: K-Kontrollmeßstelle ohne Meßinstrument
O-Örtliche Meßstelle mit Meßinstrument
-Meßstellen für Meß- und Regelanlage
P-Druck oder Zug
F-Durchfluß
T-Temperatur
L-Wasserstand/Behälterstand
Siehe auch das zugehörige Meßstellenverzeichnis!
L. & C. STEINMÜLLER
GUMMERSBACH
Anordnung der Meßstellen
R10 M 535 b

TÜV RHEINLAND

Department
for Construction Supervision

Cologne, 10.05.1983
Test No.: 211 022/1
922-wi-di

PT - ET
Eingang 1. 06. 83
2865/83
z. Erl.

REPORT
on
DAMAGE CAUSES
and
REMEDIAL MEASURES

Customer:	Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V. (DFVLR, Postfach 90 60 58, D-5000 Köln 90) Operating Agent for IEA-SSPS
Subject:	Cold storage vessel in accordance with Drawing No.: 57.32.17634/8210
Manufacturer:	VOEST - ALPINE AG
Data on vessel nameplate:	Dis- Press: 8.5 bar Dis. Temp.: 250° C MEDIUM: SODIUM Date: 1980 Vessel-No.: 5780 Capacity: 70 000 litres
Heat treatment condition:	Unannealed
Operator:	Sevillana, Spain
Site:	Almeria, Spain
Prepared by:	Dipl.-Ing. Adamsky, Dipl.-Ing. Wilters
No. of pages:	23
Figures:	1 - 13
Annexes:	1 - 3

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0.0.0 Summary

Leakages in the form of cracks had occurred in the welding seam areas of the cold sodium storage vessel, predominantly at right angles to the welding seam. Only welding seams coming into contact with sodium were affected.

SN 4, Welding seams joining the baffle plates with the vessel bottom, Annex 2.

SNR 5, Welding seams joining the repair studs with the vessel bottom, Annex 2.

SN 41/1 Manhole welding seam, Annex 2.

The other parts of the vessel did not exhibit any damages.

The following points were established:

- The base material and weld filler material clearly fulfil the requirements of the appropriate standards, the structural condition is normal. In the course of the examination, the question arose as to the tendency to temper embrittlement. Specific examinations in the Auger electron microscope confirm that there is no tendency to temper embrittlement.

- A sodium sample taken at a representative point was of reactor quality.

- The fracture surfaces of the cracks exhibit features of damage due to stress corrosion cracking. Materials, which could have caused such corrosion, were not detected on the fracture surfaches.

- It was possible to produce the same type of fracture on sample material from the vessel using hot caustic soda solution in the laboratory.

- Residual stresses exceeding the material yield point were measured at the joining weld (SNR 5), repair stud/vessel.

The laboratory examination, the test results and visual inspection of the vessel indicate that material stresses can be made responsible for the formation of the cracks:

a. Inadequate constructive design at the joining welds of the baffle plates (SN 4) and of the repair studs (SNR 5) with the tank bottom.

b. Unsuitable surface quality of the joining welds baffle plates/ vessel wall (SN 4) and the weld root of the connecting weld dished head/manhole stud (SN 41/1) on the medium side.

As a result of the inherent stability of the component areas, the constructive design deficiency listed under point a.causes high residual welding stresses, which exceed the material yield point as proved by measurements.

The residual stresses increased by the local form factor of surface notches, e.g. starting points, weld rippling of the baffle plate welding seams and, in the case of the manhole weld root, which is very irregularly welded on one side, at drops, notches and root ripples. At the ends of the baffle plate welding seams, grinding produced corners, which also lead to high stresses due to the shape.

Crack formation then occurs as the result of the inter-relations described above.

One of the main causes for the crack formation is eliminated if the residual stresses are substantially lowered and notches on the inner surface are reduced. In the former case, this is effected by means of different introduction and distribution of the sodium in the vessel which makes baffle plates un-necessary, and by subjecting the vessel to stress relief heat treatment after the repair work. In the latter case, all welding seams on the medium side are ground down to the plate surface with the exception of the weld inspection stud/ dished head (SNS 34) (Annex 3). Care was taken here to produce the smoothest possible inner surfaces by training the welders accordingly and by assessing the root formation critically.

In the course of the examination, it was not possible to find a conclusive explanation for the effect mechanism of stress corrosion cracking during operation of the vessel. The measures performed during repair work did, however, thoroughly deal with all possible ways and means of preventing the reoccurrence of such damages in the future. The vessel itself provides the indication for the positive evaluation of the repair, as it does not exhibit any cracks in the other areas, e.g. butt and stud welding seams, despite existing residual welding stresses if the surface is smooth.

1.0.0 Temporal course of the damage and elimination measures

The cold sodium storage vessel (basic diagram, Annexes 1 and 2), which has been in operation since May 1981, exhibited the following damages:

VB 1, July 28, 1981

Sodium leakage in weld area SN 4, crack at right angles to the weld, see Fig. 7.1.

This crack was bored out and covered by the stud with dished head with 170 mm Ø.

M 1, September 7, 1981, Na-leakage 2 o'clock position
M 2, September 14, 1981, Na-leakage 5 o'clock position
M 3, September 18, 1981, Na-leakage 12 o'clock postion

in the manhole weld area SN 41/1.

Pores and cracks repaired by grinding out and welding.

In January 1982, the manhole bottom was replaced by a new bottom. Prior to this, the weld areas SN 41/1 were thoroughly examined. The new welding seam was also inspected.

VB 2, January 9, 1982

Ultrasonic inspection of the 3 baffle plate weld areas SN 4.

The result indicated that all weld areas exhibited more or less large transverse cracks, which, however, did not penetrate the wall.

The stud with dished head (Ø 170 mm) was removed and the weld areas SN 4 were separated from the vessel bottom by means of severance cuts. The baffle plate area was subsequently covered by 700 mm Ø studs with dished heads.

VB = vessel bottom, M = manhole

VB 3, September 7, 1982

Sodium leakage at studs 2 and 3, see Figs. 2 and 8.

These leakages motivated the DFVLR to include the TÜV Rheinland in the search for the damage and in consultation for the elimination of the damage on the vessel itself.

The on-site examination commenced on September 10, 1982 (TÜV-Rheinland report on ascertainment of the damage, dated 27.09.1982).

In order to permit the performance of a continuous test programme, the defects were covered by makeshift cover plates, see Figs. 3 and 9.

VB 4, October 7, 1982

Sodium leakage at both gussets of the cover plate-welding seam, see Figs. 4.1 and 4.2.

Ultrasonic examination performed on the spot indicated crack growth. Consequently a renewed temporary repair and resumption of work were rejected in the interests of safety (TÜV Rheinland report on ascertainment of the damage, dated 03.11.1982).

No examinations of the cause of the damage, which could have been used for planning and assessing a promising repair, were available up to this date. Some microsections and fracture pictures of small boring cores did point to the position and course of the crack, but did not indicate the crack situation of the vessel. Some intercrystalline crack fractions, however, were partly established during these examinations.

VB = vessel bottom, M = manhole

During the period October to December 1982, stud 2 was removed for damage examinations after having drained off the sodium to approximately the upper edge of the stud. The opening was covered by a welded-on plate and the vessel was cleaned using the damp gas method (steam-inert gas) (work description Interatom Note No. 51.02501.1, dated 08.10.1982).

On completion of the cleaning, the vessel was subjected to an internal examination, the results of which are presented in Points 3.0.0 - 3.4.0.

The inspection of the vessel and the laboratory tests on the removed samples were performed parallel to each other. It appeared possible to agree to a repair of the sodium storage vessel if certain requirements were met during the repair work. Theses requirements were stated in the repair programme of the company Voest S02, S03 and in the welding plans S01, S02, S03, 6, 20, 30, 31 and 33 and were positively evaluated by Interatom, DFVLR and TÜV Rheinland.

In the report, the damages

M1 - M3 and VB1 - 2 are termed primary damages

and

VB 3 - 4 are termed secondary damages.

Damages M 1 - M 3 at the manhole welding seam were examined at Interatom.

VB = vessel bottom, M = manhole

2.0.0 Examination and activities in Almeria

2.1.0 Wall temperature measurements during operation

The approximately 3 week operating period after completion of the temporary repair (cover plates Figs. 3 and 9) was used to determine the level of the wall temperature in the damage area during operation and to establish its temporal change. The highest measured temperature amounted to 297° C in the area shown in Fig. 5 beside the forked crack on the outside of the vessel. The maximum temperature change velocity was 4.5 K/min.

The results were used for calculation examination, see Part 1 of the report.

2.2.0 Sample taking

When taking the samples, it had to be ensured that these were extracted from the vessel in such a way no damaging influences could affect the appearance of the fracture due to the contact of sodium with the environment, as for example, contact with the humidity of the ambient air. The procedure was noted in an Interatom document prior to samle taking.

Stud No. 2 was selected for taking the samples, as this contained a crack (Fig. 10, left side) which had no connection with the outside.

Stud 2 was removed with part of the vessel wall to ensure that the residual welding stresses could be measured in addition to the examination of crack formations. Furhtermore, after cleaning, two segments were removed from the manhole welding seam SN 41/1 and one austenite and one ferrite section were taken from pipe S 5.

2.3.0 Internal examination

The vessel was subjected to the following examinations after cleaning:

2.3.1 Surface crack test

The total inner surface, including the inside of stud S-5 (Annex 2) was tested in two magnetization direction, in each case both longitudinally and transversely. Alternating current yoke magnets were used. The picture was produced using fluorescent magnetic particle suspension. The Bertold test specimen was used to check the sensitivity.

2.3.2 Ultrasonic test

The ultrasonic test of the welding seams was performed with a sensitivity setting as specified in AD-Merkblatt HP 5/3. In accordance with the existing wall thickness, the substitute error value of 1.5 was taken as the basis for the registration limit. The test was effected with test angles 45° and 70° and with the normal search unit.

The longitudinal welds SN 1/1 and 1/2 were subjected to a 100 % test, the circumferential welds SN 1/3 to 1/5 in the T-joint area to a 25 % test and the manhole welding seams SN 1/6 and 3/15 to a 100 % test.

2.3.3 Inner and outer visual inspection

The visual inspection of the outside was limited to the exposed area around repair studs 1 to 3 and the manhole stud. The inner surface was subjected to a 100 % visual inspection.

2.3.4 Dimensional check

The dimensional check was performed in accordance with AD-Merkblatt HP 20 to determine the out-of-roundness and the straightness.

3.0.0 Results of the internal examination

The damages detected during the internal examination are presented in the pictures Fig. 2 to Fig. 12. The poor formation of the roout side of the manhole welding seam SN 41/1 is shown in Fig. 13.

The individual pictures are described and discussed in the following:

Annex 2 indicates the positions of the figures described below.

Baffle plate and stud area 3

Fig. 1 — Due to the fact that the stud was only welded from the outside of the vessel, the vessel warped to the inside as a result of the welding shrinkage. The maximum warping was measured as being 8 mm.

Fig. 2 — During the magnetic particle inspection of the outside, a crack was detected at right angles to the weld running parallel to the circumferential weld of the vessel just below the weld stud/vessel.

Fig. 3 — In order to perform a temporary repair, the length of the crack was determined as accurately as possible from the outside using the ultrasonic test and the ends were bored out. The entire area was covered with an overwelded plate.

Figs. 4.1 and 4.2 — After approximately 3 weeks of operation, the welding seam of the cover plate cracked on the left and on the right in the gusset.

Fig. 5

The crack on the left side of the picture above the stud on the inside of the vessel is connected with the crack on the outside of the stud, as presented in Fig. 2. It runs at a slant through the base material of the vessel bottom and ends in the circumferential welding seam SN 1/3.

On the right side of the picture there is a forked crack, which runs out at a slant from the base material into the circumferential welding seam SN 1/3. One branch of the fork ends in the welding seam, the other runs through the circumferential welding seam and ends in the base material. The crack is connected with the inside of the stud. The crack runs alongside of the welding seam SN R5 on the inside of the stud.

The sodium inlet pipe and the baffle plate can be clearly recognized. The photo was taken from the inside of the vessel looking down towards the vessel bottom.

Fig. 6

The crack, which has already been presented in Figs. 2 and 5 left side, runs on the inside of the stud to the bored out corner of the baffle plate area which was separated during repair work. A mirror was positioned in the stud to obtain the photo.

Figs. 7.1 - 7.5

After removing the baffle plate weldings from the vessel wall, these were subjected to a magnetic particle inspection. The pictures were obtained using black magnetic particles on white contrast colour. The transverse cracks which were detected and are identified in detail in the pictures are located at notches. The crack displayed in Fig. 7.1 caused the first vessel leakage (VB 1). The visible boreholes, some of which are closed by plugs, are points where attempts were made to bore out the end of cracks, or where boring cores were removed for examination.

Baffles plate and stud area 2

Fig. 8

A cross-shaped branched crack, which could be covered with a disc of 5 mm Ø, was detected in the weld metal of the stud welding seam SN R 5 during the magnetic particle inspection.

Fig. 9

Crack, Fig. 8 covered with plate during temporary repair.

Fig. 10

The crack in the centre of the picture, which is connected with the corner of the cut-out, shows the course of the crack from Fig. 8 inside the stud.

The crack presented on the left side had not penetrated through to the outside of the vessel. The later fractographic examinations were performed on this crack.

Baffle plate stud area 1

Fig. 11

Crack on the inside of the stud, which had not penetrated through to the outside of the vessel.

Fig. 12

Cracks at the ends of the inadequately ground weldings of the baffle plates.

Manhole welding seam

Fig. 13

Remainder of the root of the manhole welding seam SN 41/1 after severance of the dished head. Severe drops are evident.

3.1.0 Surface crack test (Point 2.3.1)

No crack indications were detected outside the areas listed in the preceeding description of the pictures. It was not possible to accurately inspect the root side of the manhole welding seam due to the notch-covered surfaces. It did, however, exhibit transverse cracks, which did not penetrate the welding seam, at several points on the circumference.

3.2.0 Ultrasonic test (Point 2.3.2)

Indications subject to registration were not detected in either the tested butt welds or in the welding-in seam of the manhole.

3.3.0 Inner and outer visual inspection (Point 2.3.3)

The inner and outer surfaces were covered with a slight rust film, which, however, did not impede the evaluation.

All welding seams were ground with the exception of the baffle plate welding seam SN 4 on the inside underneath the baffle plates and the root side of the manhole welding seam SN 41/1.

3.4.0 Dimensional check (Point 2.3.4)

The requirements specified in AD-Merkblatt HP 20 and the results of the measurements are listed in Annex 3. The results of the measurements are in the lower tolerance range of the requirements.

4.0.0 Summary of the examination results

The results of the diverse examinations performed are briefly summarized below:

4.1.0 Damage situation of the vessel on site

4.1.1 The welded joint baffle plate/vessel wall exhibits cracks at right angles to the welding seam at all 3 baffle plates. These originate from surface notches, sharp corners and edges. The crack frequency on the outer ground side of the welding seams is lower than on the unground inner side, which was not adequately accessible for welding and, above all, grinding due to the spatial conditions.

4.1.2 The transverse cracks detected at the welding seam manhole stud/ dished head are also related to surface notches on the medium side, which, in the form of drops, root notches, weld ripples and root concavity generally cannot be avoided in seams which are welded on one side. In the case in question, however, the root of the weld was welded in a particularly irregular manner.

The amages described in 4.1.1 and 4.1.2 have been termed "primary damages" in the discussions held to date, as they obviously occured during vessel operation prior to the repair measures.

4.1.3 The cause of the crack damages, which appeared in the welding seam area of the repair studs after the repair, is obviously linked with the corners of the cut-out web areas of the baffle plates, which are nearest to the jointing weld repair stud/ vessel. Points of high stress concentration occur here due to the addition of residual stresses from welding in the studs, load stresses due to internal pressure and thermal stresses (Annex 2).

4.2.0 Report on the calculation examination of the damaged cold storage vessel dated 19.11.1982

The stresses occurring in the cold storage vessel are to be determined according to the rules in the AD-Merkblätter and evaluated with reference to the existing damages.

In addition to the stresses resulting from internal pressure, the temperature stresses are determined for several stress conditions.

The maximum reference stresses resulting from static loading are lower than the high temperature yield point of the material both with and without consideration of the repair studs. An estimate of the load cycles results in approximatelx 185 000 load cycles up to cracking. The results of the examination show that there is no static and dynamic overloading of the material for correct execution and compatibility of the media.

4.3.0 Examination report on residual stress measurements performed on the cut-out stud area by the Institute for Materials Testing dated 20.01.1983

Using the part with welded-on stud which was removed from the vessel, the residual stresses were determined at the longitudinal and transverse sections of the intersection of the vessel and the stud by means of the borehole process. (Figs.8-10)

The highest residual stress was in longitudinal direction and amounted to σ_{eil} = 400 N/mm² on the inside of the vessel opposite the stud wall. Clear deformation of the vessel wall could be observed in this area (Fig. 1). This can be traced back to warping resulting from welding.

4.4.0 Report on the damage examination of the cold storage vessel by the Institute for Materials Testing dated 11.03.1983

The examined cracks exhibit the features of damage due to stress corrosion cracking in both the metallographic and the fractographic findings. In each case the cracks originated from notches and smaller welding flaws or the structure of the weld surface on the side in contact with sodium.

In additions, the position and direction of the cracks point to a connection with residual welding stresses, which, as is well known, can exceed the material yield point in dimensionally stable areas. The vessel had not been subjected to stress relief heat treatment.

5.0.0 Summary and evaluation of the examination results with reference to the cause of the damage

Both the crack formations which occurred prior to repair in the baffle plate area and at the manhole welding seam, and those which occurred after the repair in the area of the joining welds repair stud/vessel all exhibit clear features of intercrystalline stress corrosion cracking. The cracks were only located on the inside of the vessel coming into contact with the medium near faults resulting from the design and the manufacture.

The material 15 Mo 3 is present and must be accepted in its quality as steel which is not completely resistant to cracking in caustic solutions. It is up to research to offer an explanation for the medium side. Indications for this are given in the report included under 4.4.0. Subsequently, in order to evaluate the cause of the damage, it only remains to discuss the stress necessary for crack formation, which comprises residual stresses due to welding, load stresses due to internal pressure and temperature differences as well as peak stresses from notches caused by the design and the manufacture.
The various areas of damage are discussed in the following from these points of view:

5.0.1 Joining welds baffle plae ribs/vessel wall (SN 4)

The permanent connection of the baffle plates via ribs with the vessel wall in the base of the casing creates a dimensionally stable component area, in which high residual welding stresses and peak stresses form due to the operating stresses (pressure and temperature) (Annex 2).

This is superposed by an unfavourably selected manufacturing programme, which prevents both orderly welding and a complete non-destructive test.

It was possible to reconstruct the manufacturing sequence as follows:

First of all, the K-welds baffle plate and the two ribs were manually welded. This component was then placed on the bottom of the vessel casing and was initially welded from the inside and then, after grooving out, from the outside. It was possible to grind and inspect the outer side of these welds, but not the inner side. In view of the fact that the box, which is open at the short ends is only 50 mm high and 300 mm long, the welding of the inner side was executed under such limited spatial conditions that the weld surfaces covered with spatter and notches, as shown in the relevant pictures, just could not turn out otherwise.

Furthermore, this surface condition does not comply with the requirements of the General Specifiaction RVS CRS-02 dated 15.03.1978, which contains the following requirement on page 5 under Point 4 "Surface Conditions of the Welds":

> "At the pressure-loaded components, all longitudinal, circumferential and weld-in seams shall be grinded- if possible - from inside to be free of notches".

Thereby the limitation "if possible" is understood as applying to welds, which are not accessible form the inside due to the dimensions of the component (e.g. a pipe of 500 inner Ø) and which can therefore only be welded from the outside. On the basis of the knowledge which can be drawn from the damage in question and which confirms this regulation, all possiblilties should have been exhausted during design an construction to guarantee notch-free surfaces on the inside of the components.

Even if one had not wanted to dispense with baffle plates which were permanently welded to the vessel wall, despite other and simpler design possibilities, then an altered welding sequence would have easily made it possible and feasible to completely grind over the welded joint at the pressure-loaded wall, thus making it free of notches, and to inspect it. Moreover, it would have been quite adequate to fix the baffle plates with much shorter welds in order to moderate the inherent stability of these component areas, which are loaded with thermal stresses due to the temperature differences.

5.0.2 Manhole welding seam (SN 41/1)

As far as the surface quality is concerned, the same is valid here as in the case of the baffle plates. In the General Specification mentioned above, the application of TIG-welding is stipulated for the roots, apparently to ensure that weld roots coming into contact with the medium as are smooth as possible. The weld formation discovered on the inside neither complies with this regulation nor with the requirements of the AD-Merkblatt HP 5/1 nor with the requirements of the quality class B according to DIN 8563, Part 3, where only flat local root concavities and notches are admissible over seams welded on one side, bute where incomplete penetration of the root is inadmissible.

5.0.3 Repair studs

The form of repair which was selected and the thickness of the stud wall which, with 27 mm is much thicker than the 16 mm vessel wall cause additional residual welding stresses in the vessel bottom area. These are superposed by considerably impaired thermal expansions in the stud area. Additional points of high stress concentration were produced in the corners due to the design of the severance cuts (Annex 2).

5.1.0 Comprehensive evaluation

The results of the examinations can be comprehensively evaluated as follows:

- Both the material of the vessel and the selected weld filler materials clearly fulfil the requirements of the appropriate standards. In the course of the examination, questions arose as to the tendency to temper embrittlement. Although this was hardly probable due to the low phosphorus content, specific examinations in the Auger electron microscope confirmed that there is no tendency to temper embrittlement.

- Outside the damage areas, the vessel is in perfect conditions as regards the welding seams and the total inner surface. A complete magnetic particle inspection performed with the highest possible sensitivity did not exhibit any further crack indications. The ultrasonic test of the butt welds did not result in any indications subject to registration.

- A sodium sample taken at a representative point was of reactor quality.

- The fracture surfaces of the cracks and the course of the cracks in the material structure exhibit the features of damage due to stress corrosion cracking. Materials, which could have caused such corrosion cracking, were not detected on the fracture surfaces.

- It was possible to produce the same type of fracture on sample material taken from the vessel using hot caustic soda solution.

- The constructive design of the joint baffle plate/casing base is not consistent with perfect execution of the welding work and with the reasonable demand for a notch-free, ground inner surface. Furthermore, it causes the build-up of a high residual stress level due to its inherent stability.

- With reference to the root formation, the welding seam manhole stud/dished head does not comply with the specifications. Sharp notches, incomplete penetration and svere drops produced an inner surface covered with notches.

- The formation of the repair studs and the design of the severance cuts for separating the cracked areas created additional high residual stresses and high stress concentrations. Residual welding stresses, which with a maximum of 400 N/mm² exceeded the material yield point, were measured in the stud removed for the examination (yield point at design temperature 285° C: K = 205 N/mm²).

The laboratory examinations, the test results and the visual inspection of the vessel indicate that material stresses can be made responsible for the formation of the cracks described above:

a. Inadequate constructive design at the joining welds of the baffle plates (SN 4) and the repair studs (SN R5) with the tank bottom, and

b. Unsuitable surface quality of the joining welds baffle plates/vessel wall (SN 4) and the weld root of the connecting weld dished head/manhole stud (SN 41/1).

Due to the inherent stability of the component areas, the constructive design deficrency listed under point a. causes high residual welding stresses, which exceed the material yield point, as proved by measurements.

The residual stresses increased by the local form factor of surface notches, e.e. starting points, weld rippling of the baffle plate welding seams and in the case of the manhole weld root, which is very irregularly welded on one side, at drops, notches and root ripples. At the end of the baffle plate/rip welding seams, grinding produced corners, which also lead to high stresses due to the shape.

Crack formation then occurs as the result of the interrelations described above.

6.0.0 Reapir of the vessel

6.1.0 Prerequisites for repair

On the basis of the results of the examination described above, the following principles were established for the repair:

- Avoidance of welded-on parts on the inside of the vessel.
- Avoidance of temperature loading in the bottom area due to a design change in the sodium inlet.
- Maximum accuracy in the preparation of the welding edges to minimize warping due to welding and the residual welding stresses, root gap $\leqq$ 2 mm.
- Stress relief heat treatment of the vessel, if feasible welds on the inside ground down to the plate surface, but at least smoothed by grinding on the inside.
- Observation of the welding shrinkage during welding.
- Requirements on

  Out-of roundness $<$1 % without heat treatment
  $<$2 % with heat treatment (HP 20)

  Straightness $<$0.5 % independent of with or without heat treatment
- Hardness values in the heat affected zone $\leqq$ 250 HV 10, if not subjected to heat treatment.

The above requirements were entered in the repair programme of the company Voest S02, S03 and in the welding plans S01, S02, S03, 6, 20, 30, 31 and 33.

6.2.0 Execution of the repair

The repair work was executed in the period 10.01.1983 to 23.02.1983. The damage areas were removed with a large safety margin. The new part of the casing base to be welded in measured 4500 mm x ~1500 mm. Measurements performed on a work specimen supplied higher hardness values than specified. Due to handling errors when welding the electrodes, larger areas had to be repaired because of too high pore frequency. On the basis of these observations made during the repair work on 20.01.1983, it was determined that the vessel as a whole should be subjected to heat treatment. The high residual stresses measured at the vessel part also played a role in this decision (see 4.3.0).

6.3.0 Evaluation of the repair (Annex 3)

Employees of the TÜV Rheinland performed the following activities during supervision of the repair work:

- Complete supervision of the fitting and welding work.
- Assessment of the X-ray films, performance of surface crack tests and ultrasonic tests.
- Control of the heat treatment.
- Construction test and pressure test.

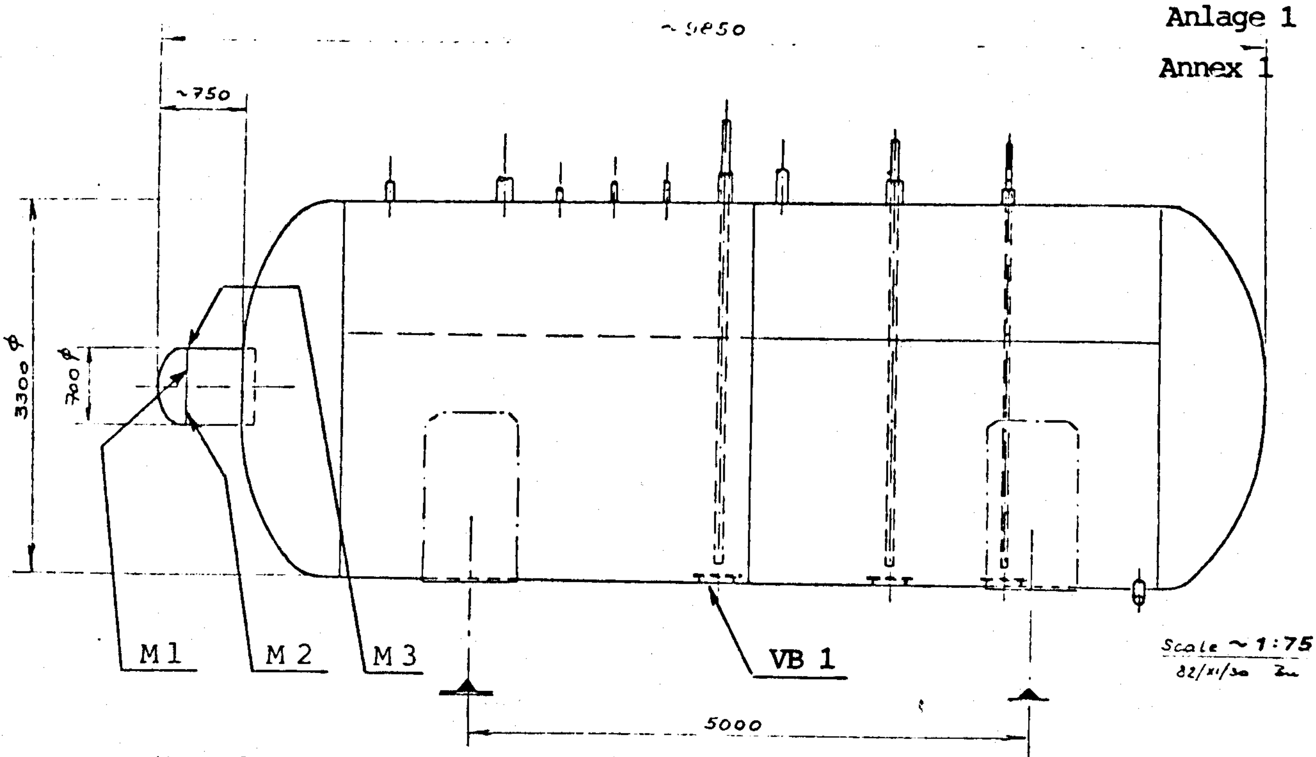
It is confirmed that the repair work performed fulfils all the prerequisites for equating the vessel with a new vessel.

Technischer Überwachungsverein Rheinland e.V.
Zentralabteilung
Bauüberwachung von Großanlagen
Der Sachverständige

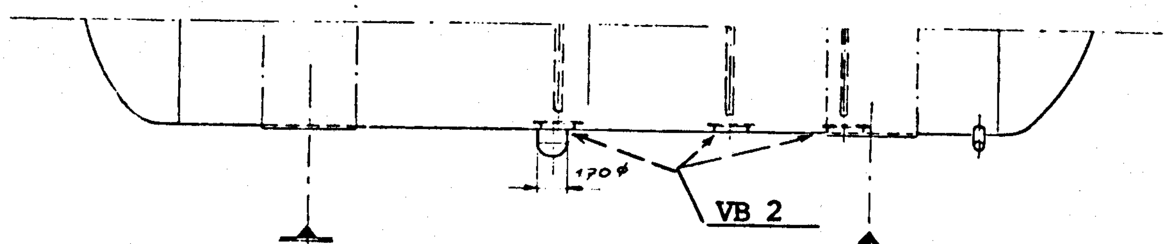
(Dipl.-Ing. Wilters)

Anlage 1

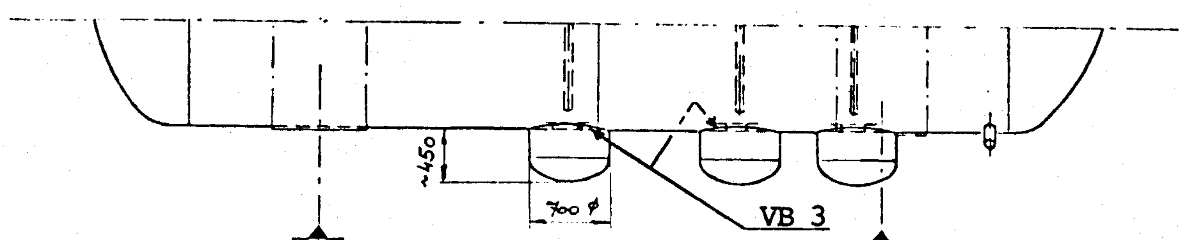
Annex 1



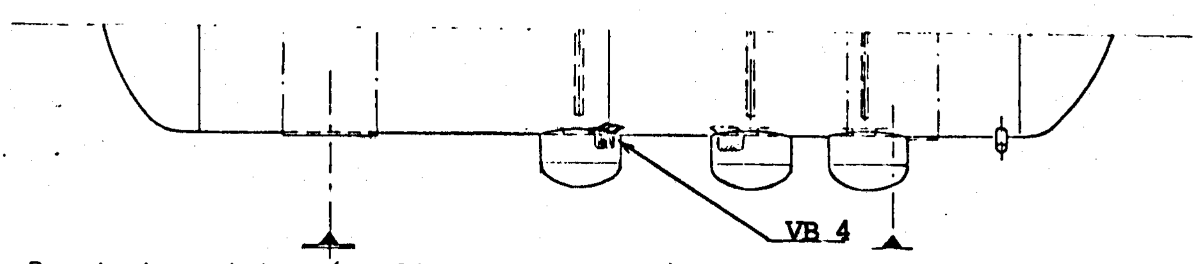
Vessel as designed and location of first cracks



After first repair (170 mm Dia. bowl) and crack indications



After second repair (3 domes) and cracks in these domes

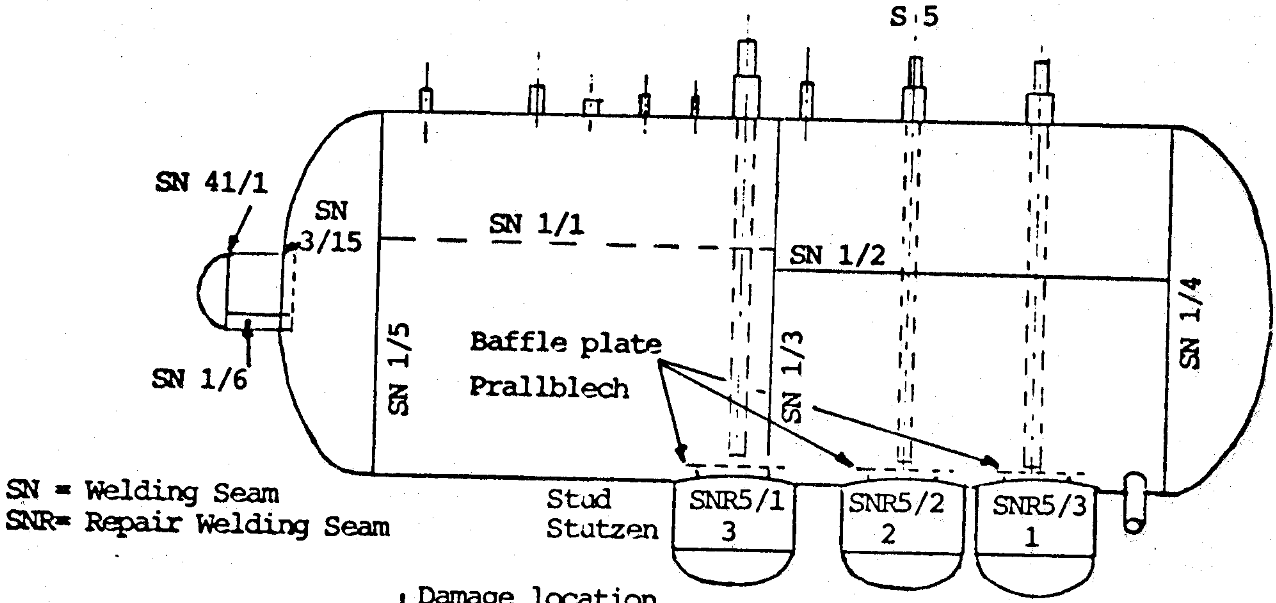


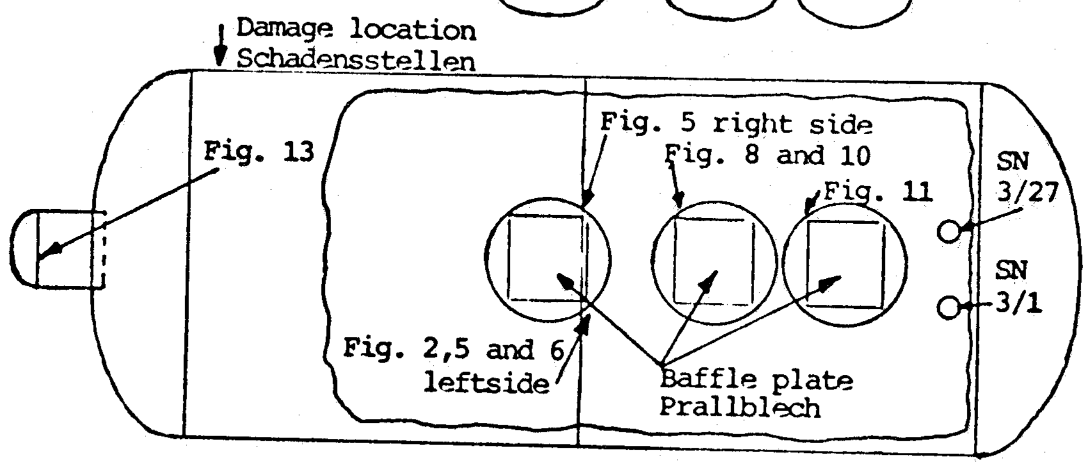
Repair by patches (preliminary measure) and cracks at the edges

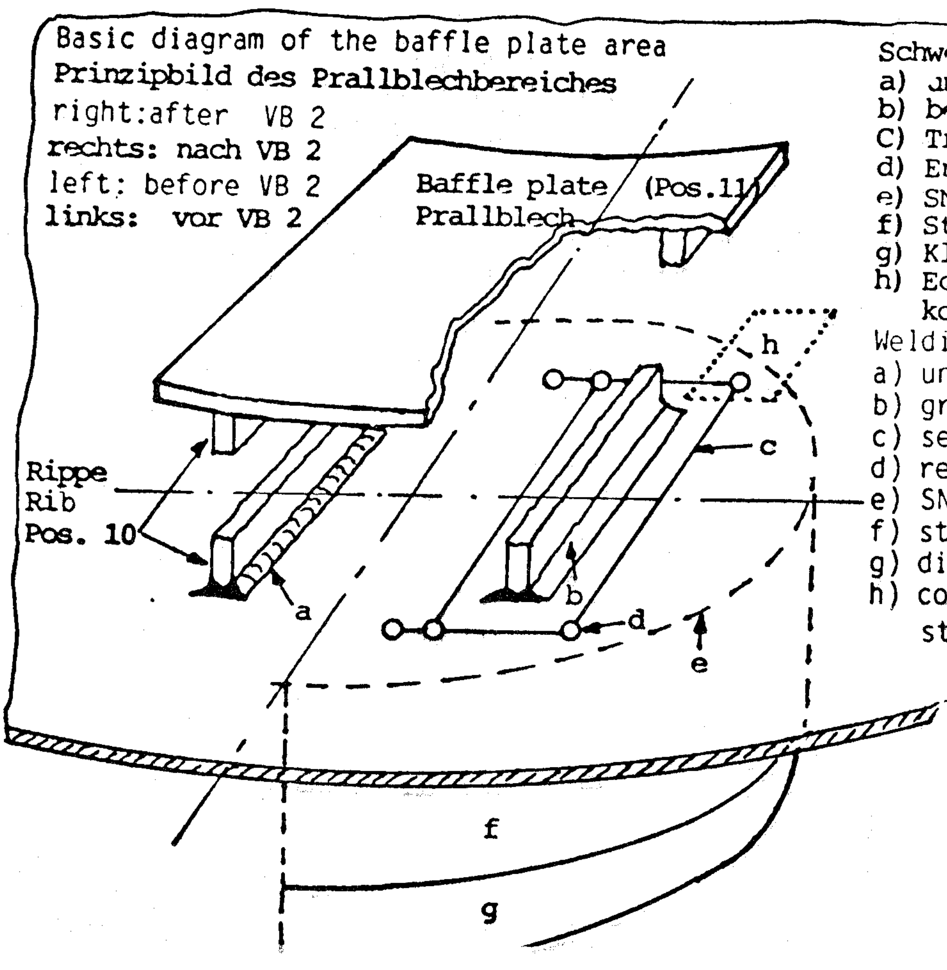
FIGURE : <u>COLD STORAGE TANK</u>

Crack indications and different phases of repair

Anlage 2
Annex 2

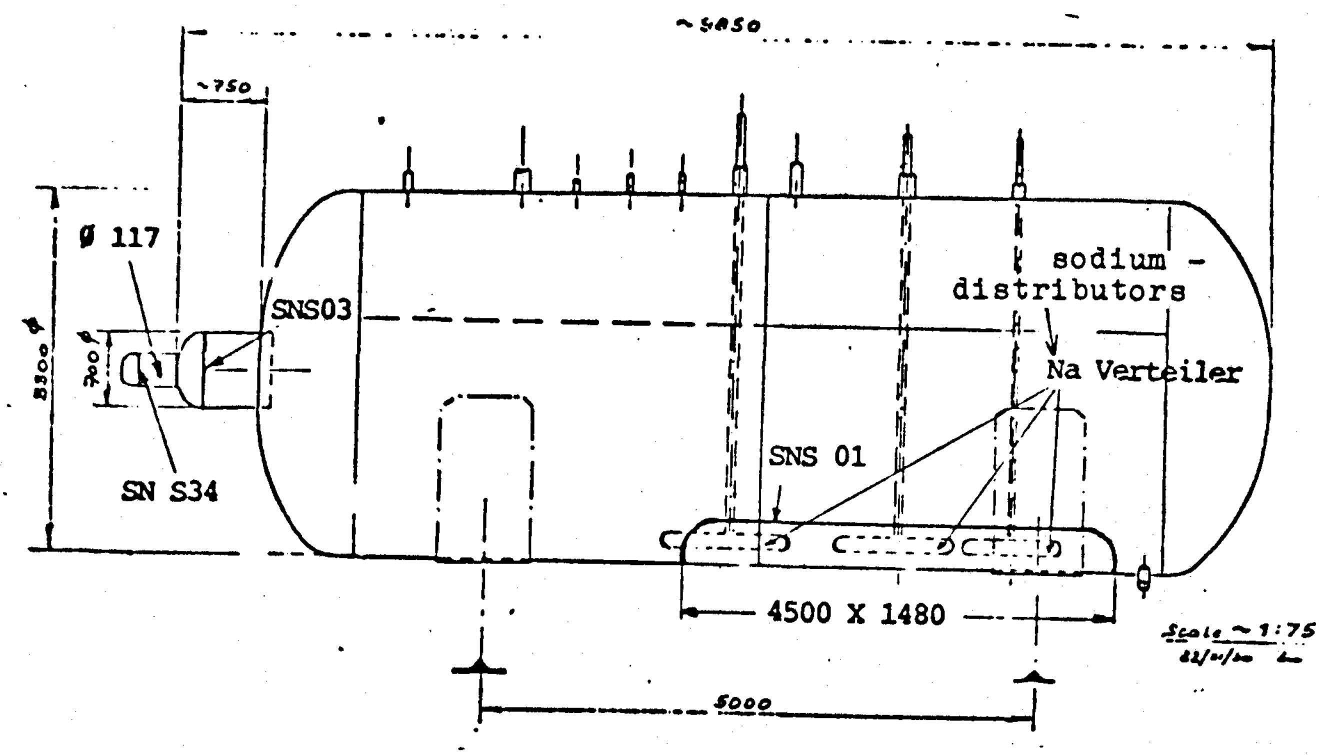






Schweißnaht SN 4
a) unbeschliffene Seite
b) beschliffene Seite
C) Trennschnitte
d) Entlastungsbohrungen
e) SNR 5
f) Stutzen
g) Klöpperboden
h) Ecken hoher Spannungskonzentration

Welding seam SN 4
a) unground side
b) ground side
c) severance cuts
d) relief boreholes
e) SNR 5
f) stud
g) dished head
h) corners of high stress concentration



Vessel after the repair:

Behälter nach der Reparatur:

- Inner surface ground down to the plate surface in the area around SN S01 and SN S03
- Innenoberfläche blecheben beschliffen im Bereich der SN S01 und SN 03.
- Installation of sodium distributors with sodium - outlet to the top
- Einbau von Na-Verteilern mit Na-Austritt nach oben.
- Regidity
- Formhaltigkeit

Requirement according to AD-Merkblatt HP 20 Anforderungen nach AD-Merkblatt HP 20	Out-of-roundness ≦ 2 % related to the vessel diameter ≙ 66 mm Unrundheit ≦ 2 % bezogen auf den Behälterdurchmesser ≙ 66 mm	Straightness ≦ 0.5 % of the cylindrical length ≙ 36.3 mm Geradheit ≦ 0,5 % der zylindrischen Länge ≙ 36,3 mm
Prior to repair Vor der Reparatur	8 mm	7 mm
After repair Nach der Reparatur	26 mm	10 mm

INSTITUT FÜR MATERIALPRÜFUNG UND CHEMIE

Prüf-Nr.:

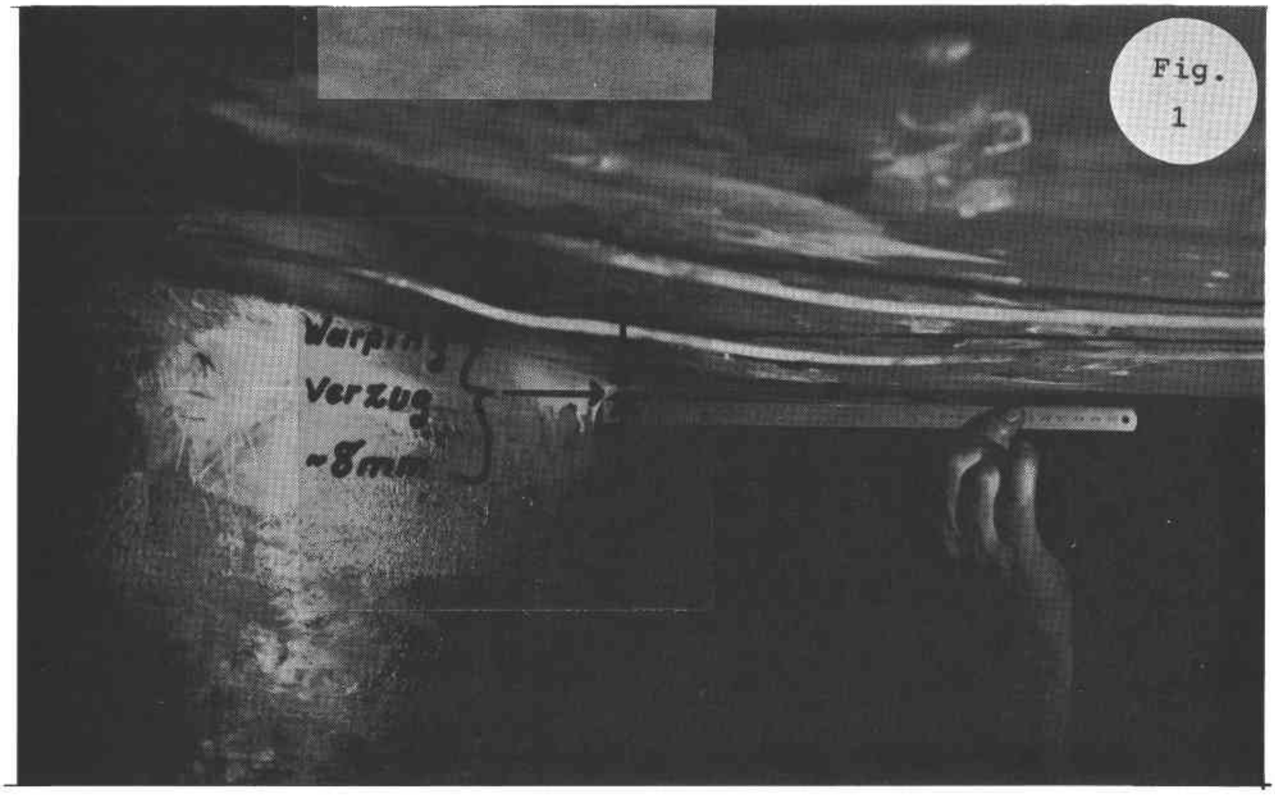



Fig.
3

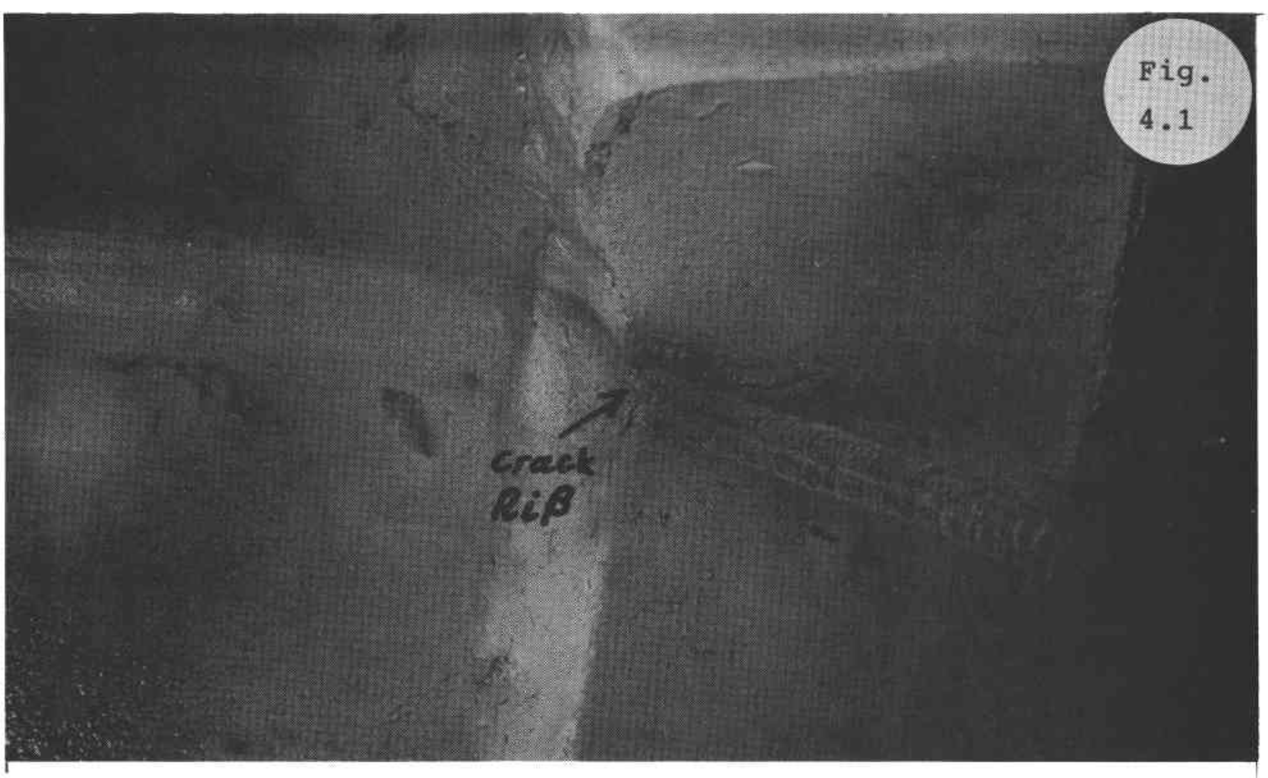


Fig.
4.1
Crack
Riß


Fig.
4.2
crack
Riß


Fig.
5
crack
Riß
Riß
Welding Seam
Schweißnaht

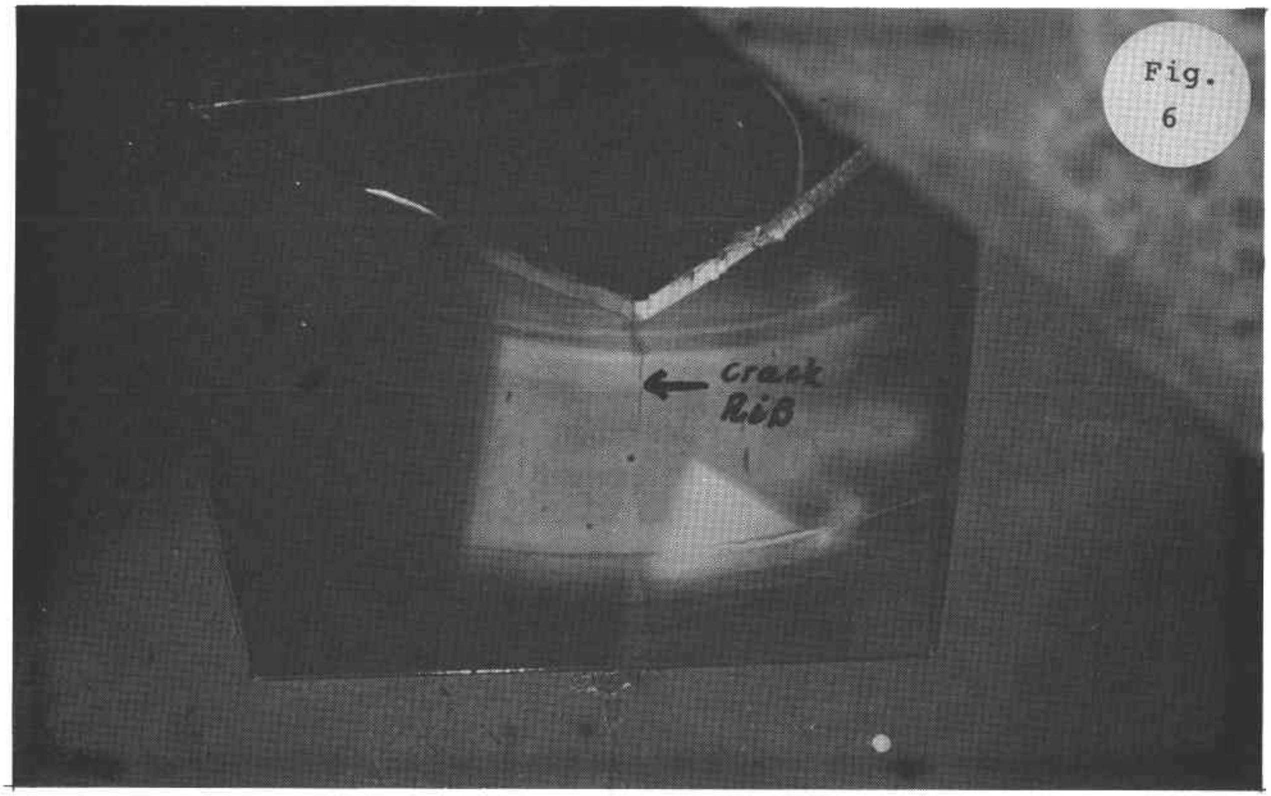


Fig. 6

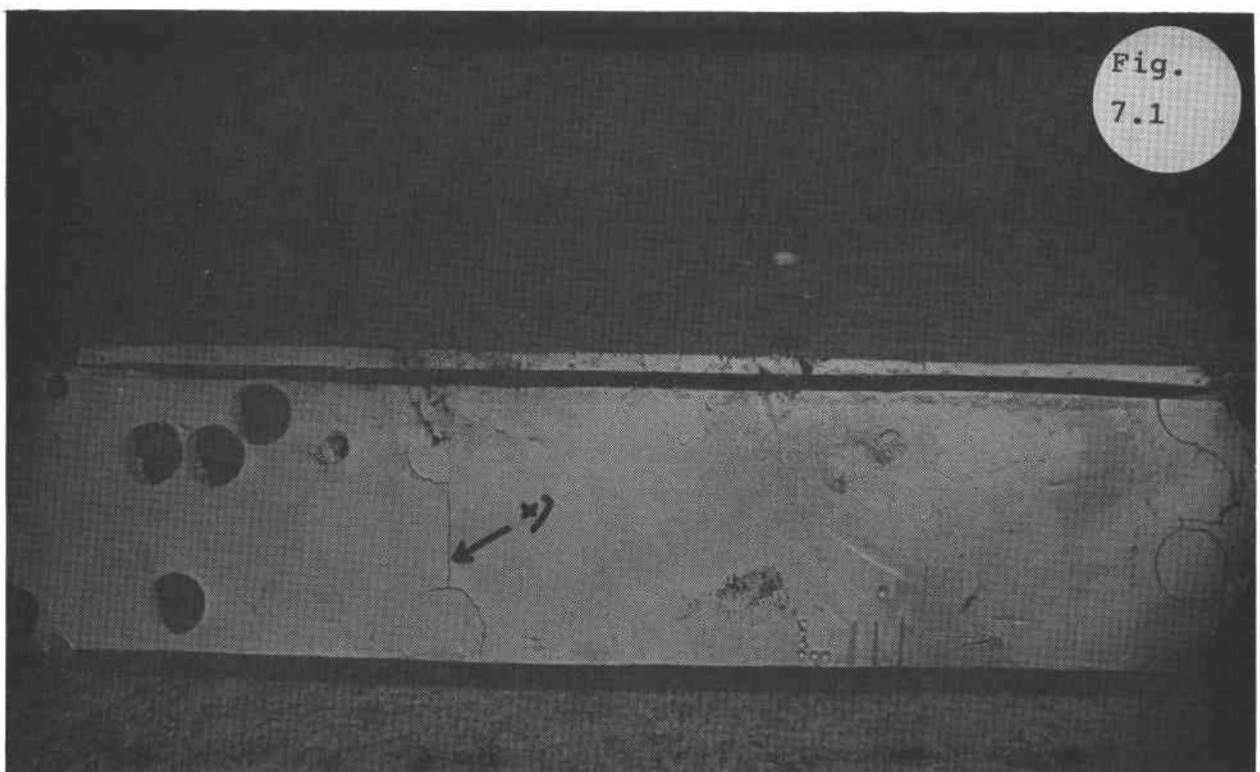


Fig. 7.1

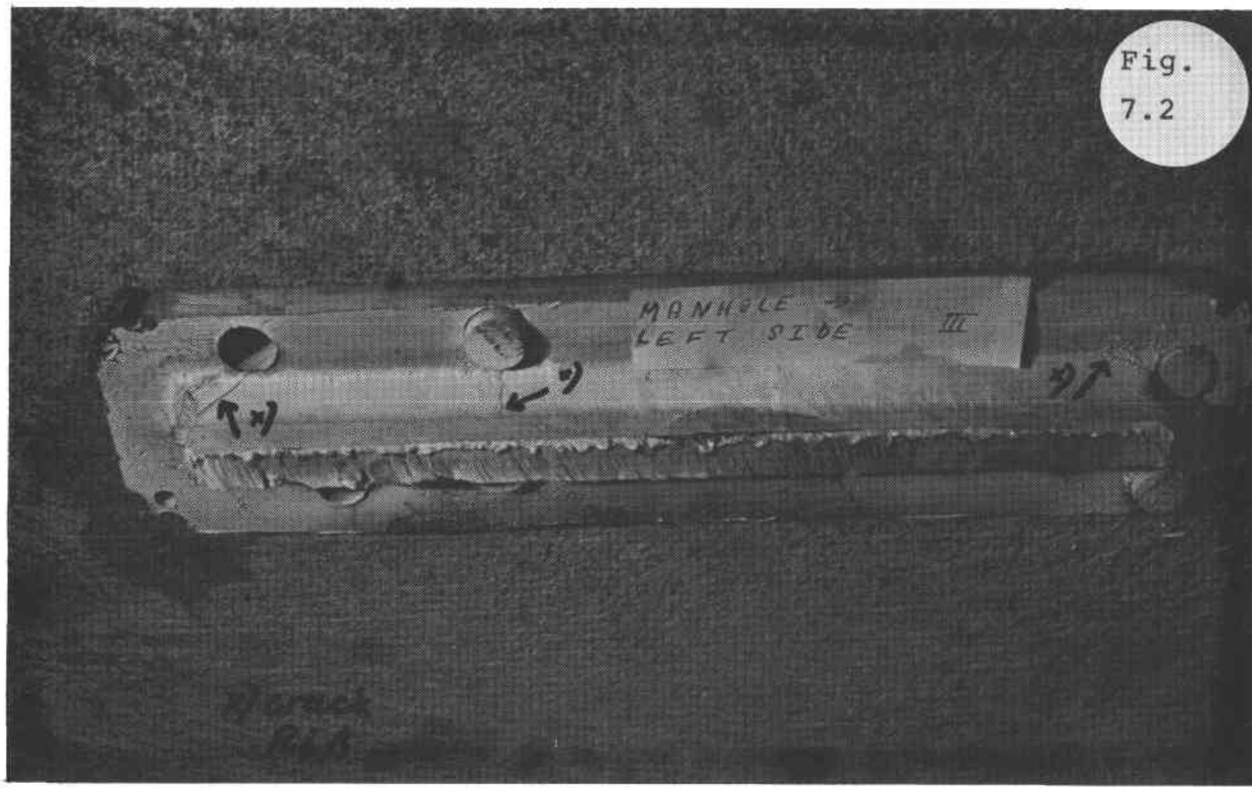


Fig.
7.2
MANHOLE
LEFT SIDE III

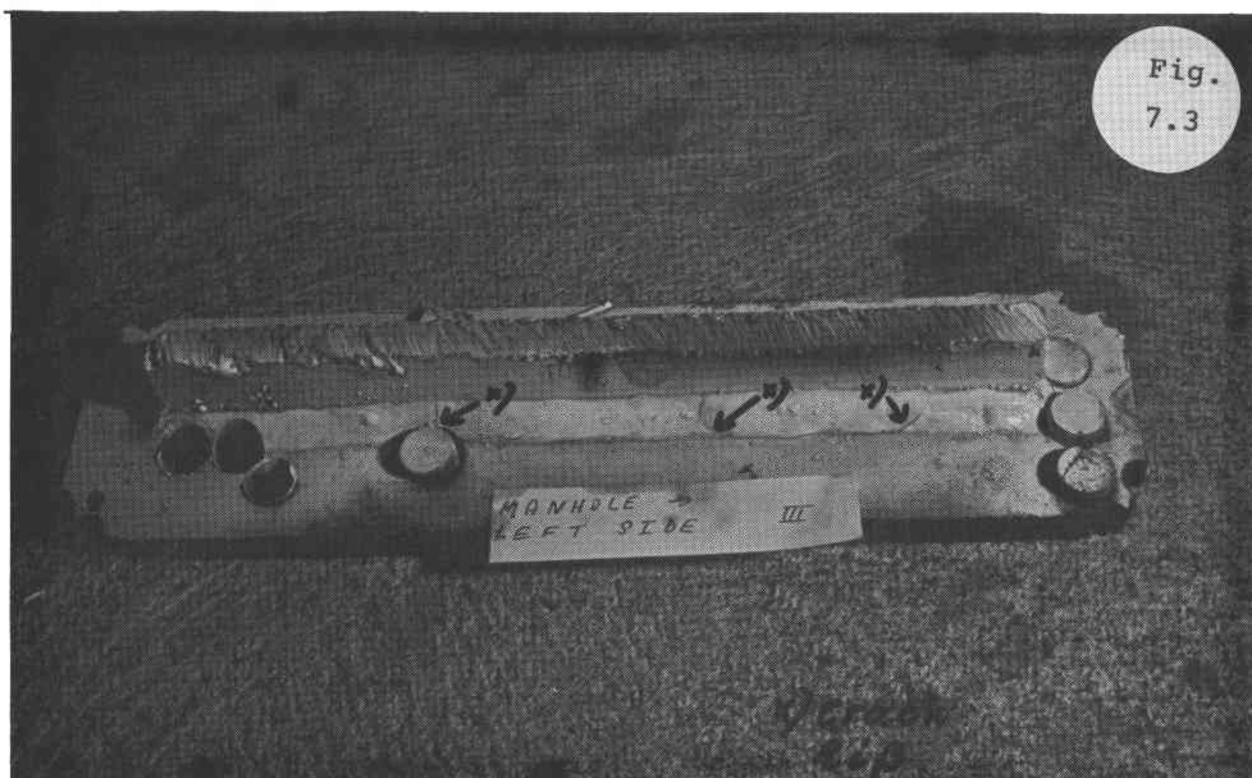
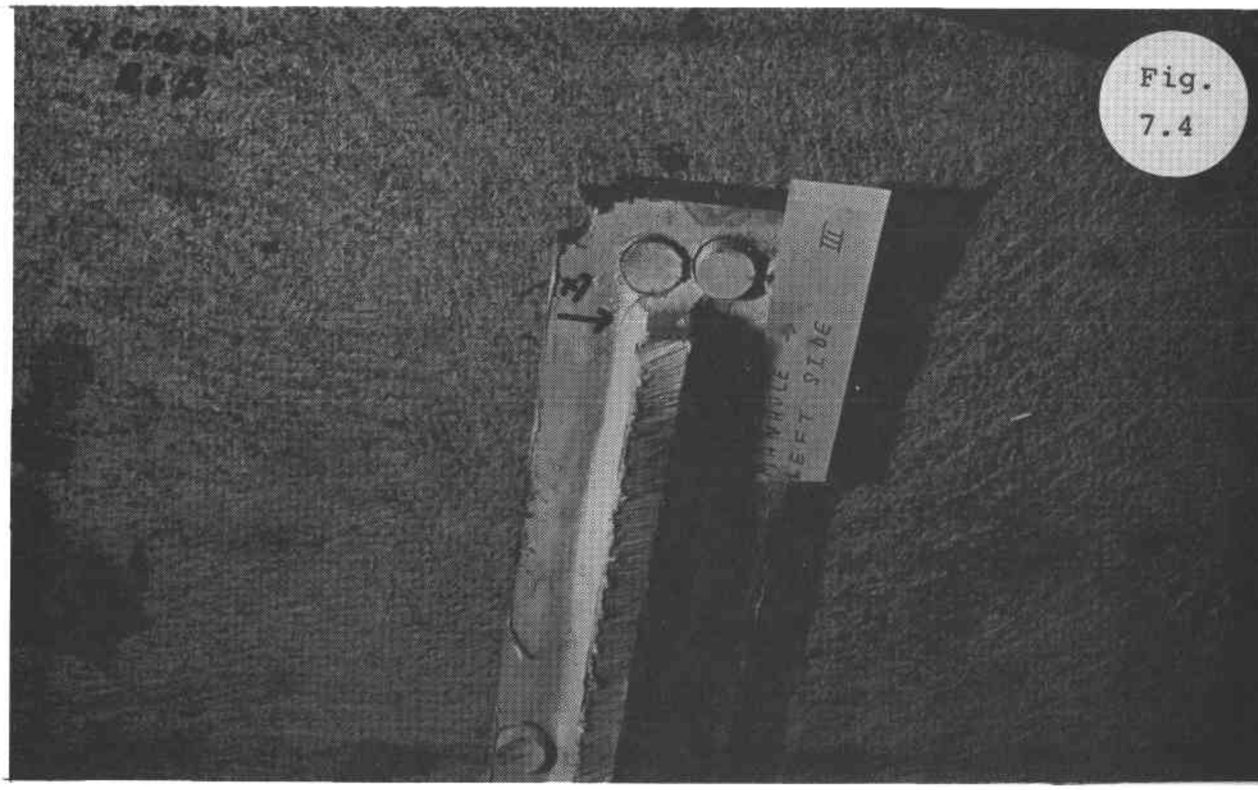


Fig.
7.3
MANHOLE
LEFT SIDE III


x) Crack
Riß
Fig.
7.4
x)
MANHOLE →
LEFT SIDE
III

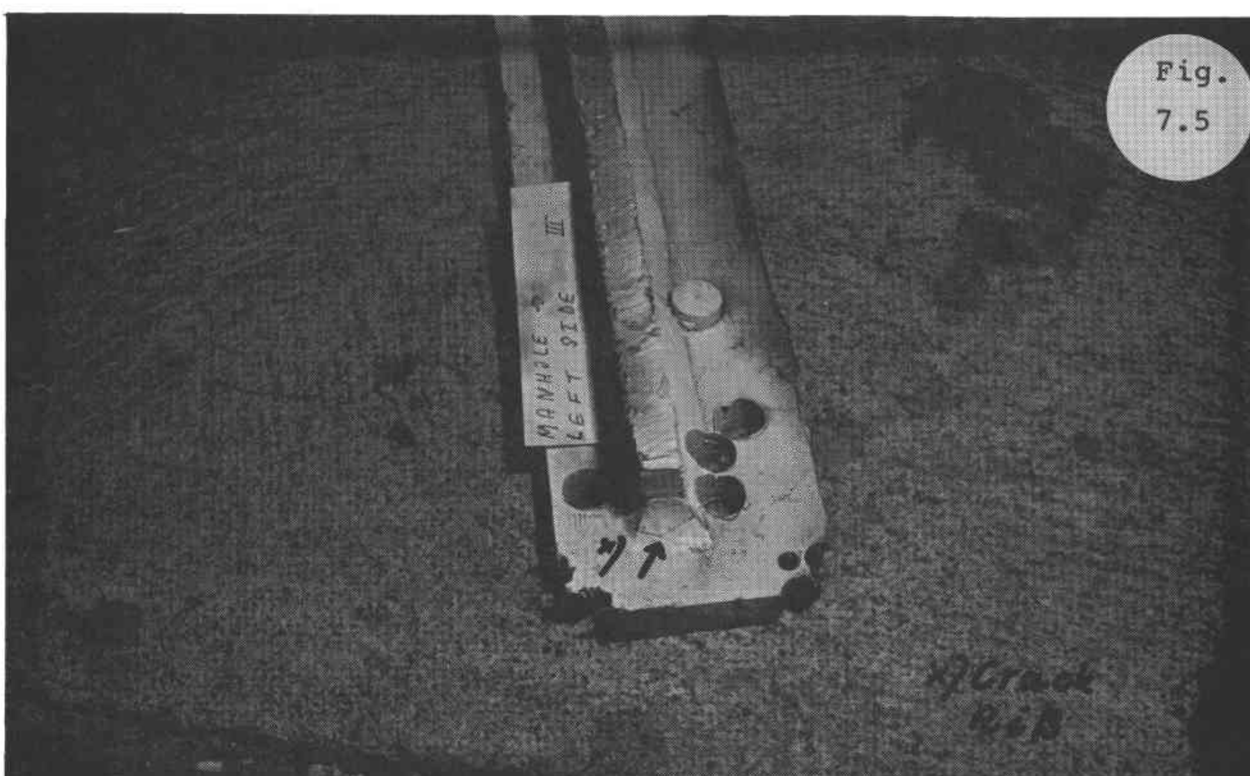


Fig.
7.5
III
MANHOLE →
LEFT SIDE
x)
x) Crack
Riß


Fig.
8
Crack
Riß

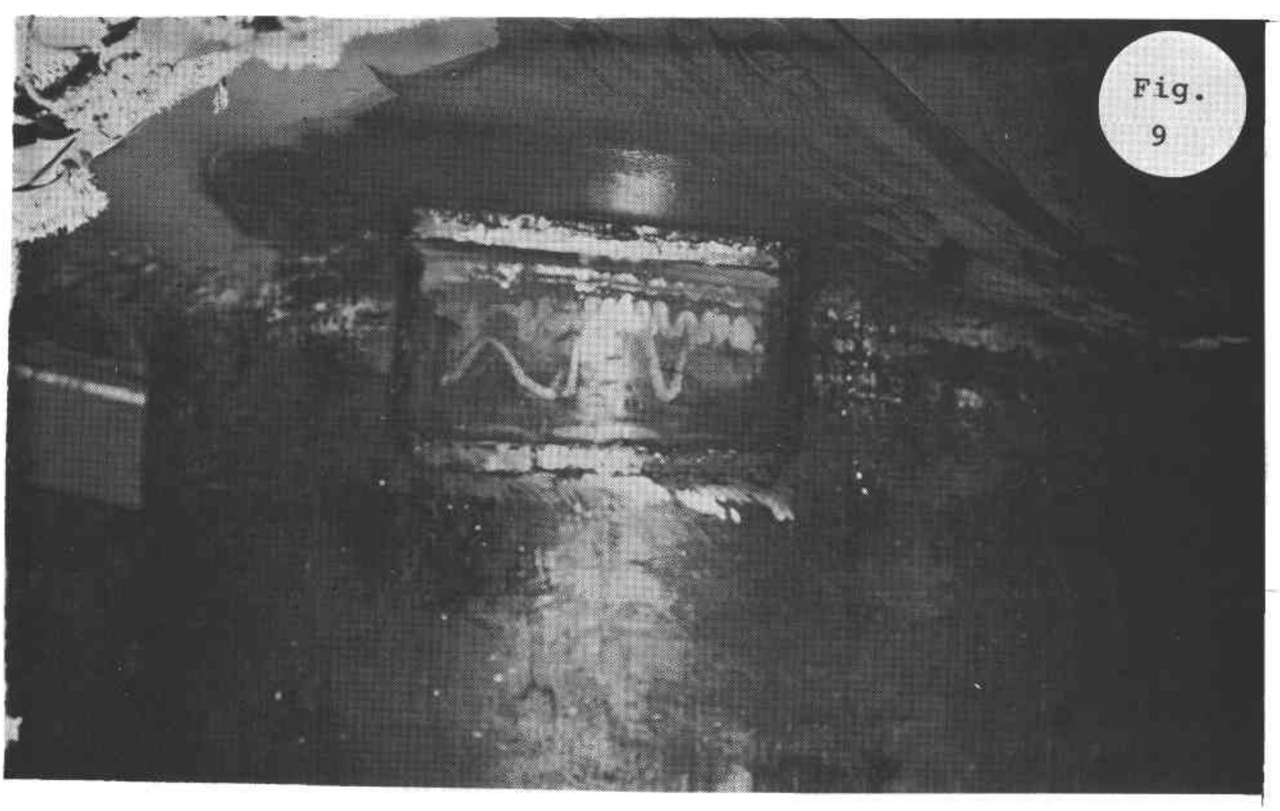


Fig.
9


Fig.
10
Crack
Riß

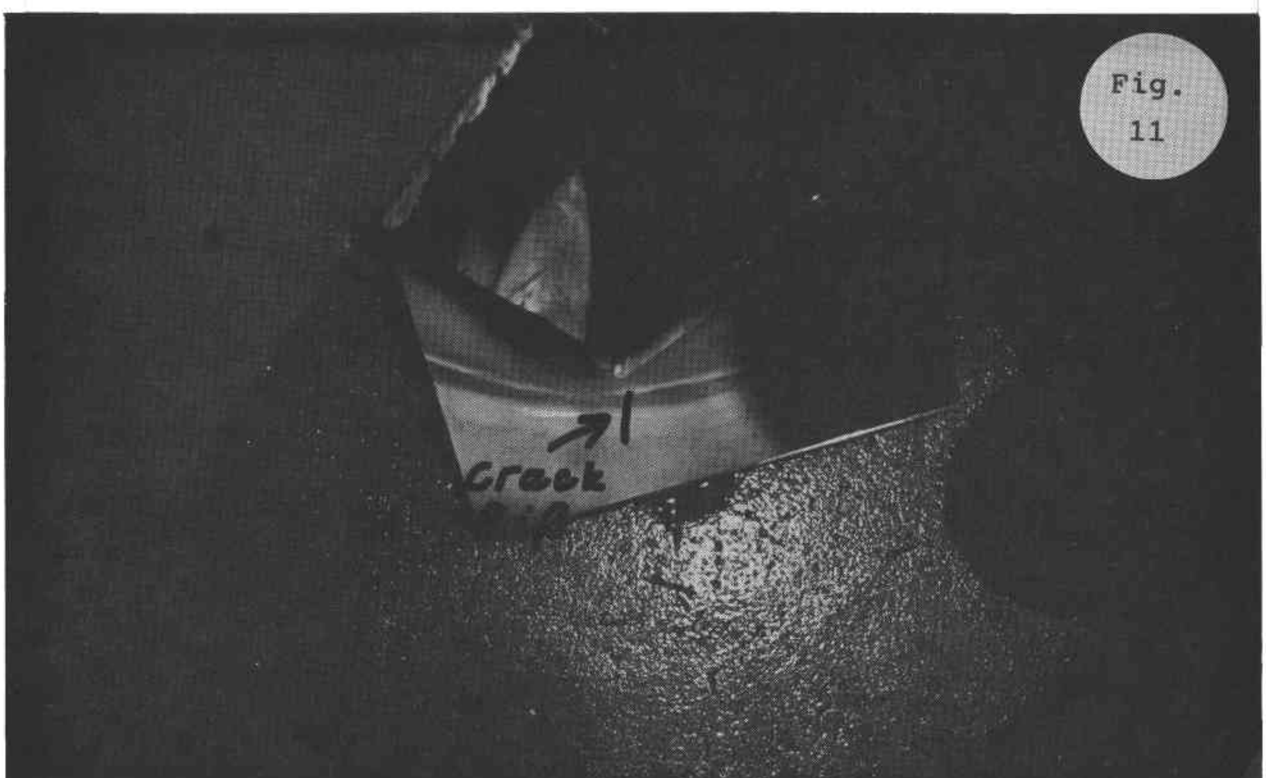


Fig.
11
Crack

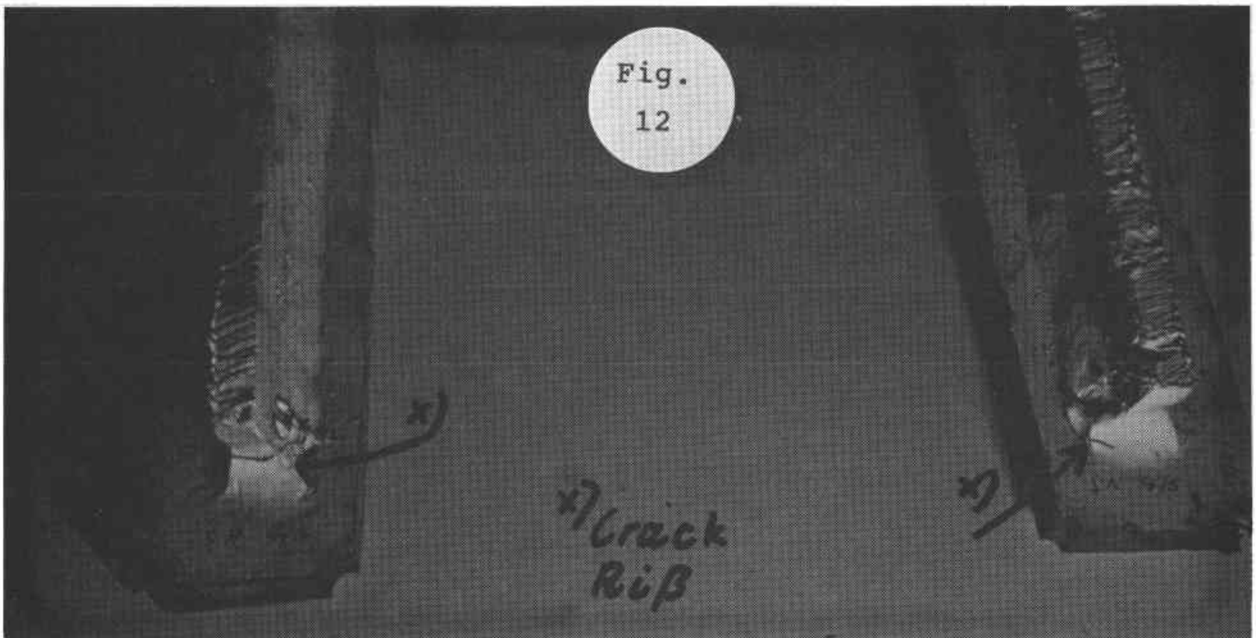


Fig.
12
x) Crack
Riß
x)
x)

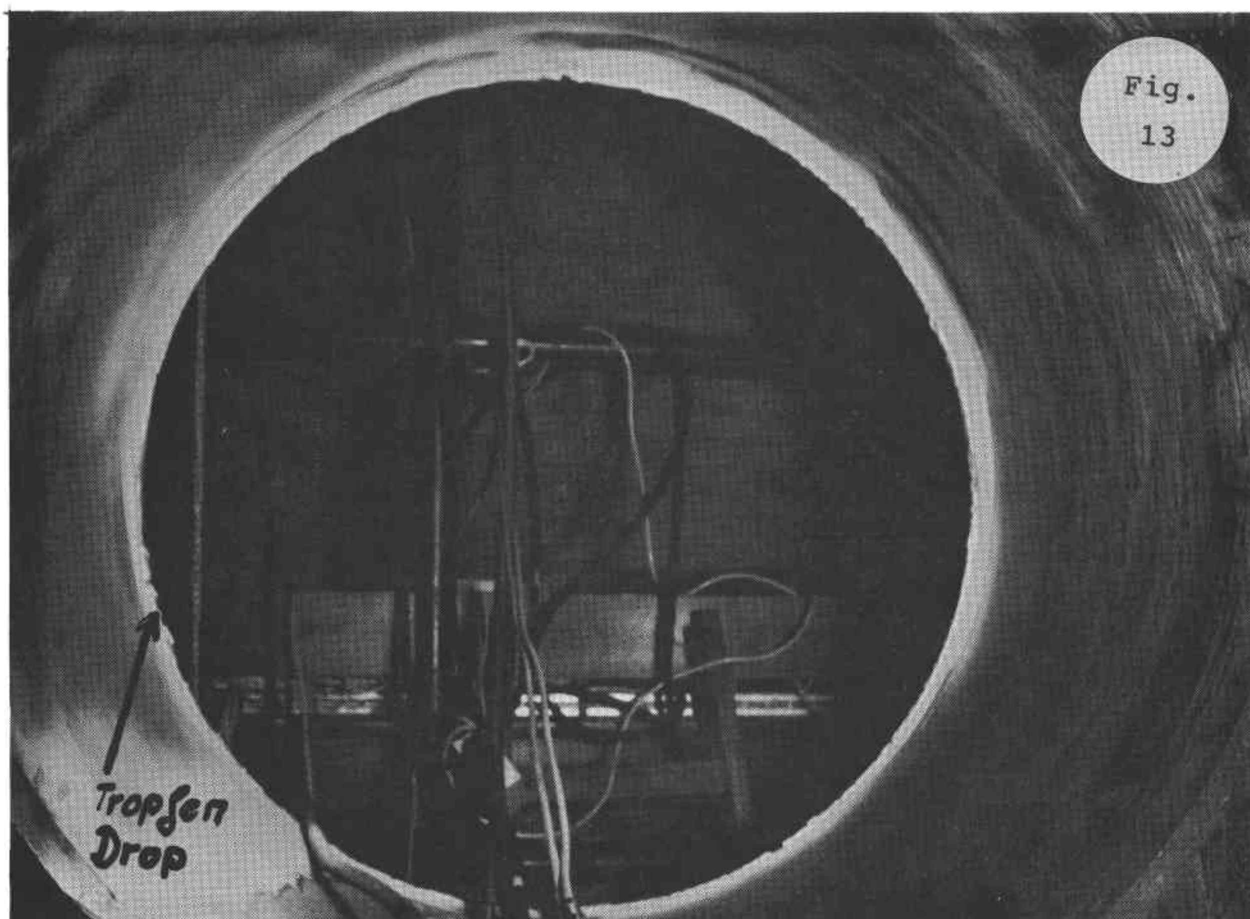


Fig.
13
Tropfen
Drop

TÜV RHEINLAND

INSTITUT FÜR MATERIALPRÜFUNG UND CHEMIE

5000 Köln 91, den 11.3.1983

Test No.: W 323/82

923-dl-schn

Report
on
the Damage Examination of the Cold Storage Vessel

Customer :	Department for Construction Supervision
On behalf of:	Solar Power Plant Almeria
TÜV Order No.:	922-211022/01 W 323/82
Order dated:	27.10.1982
Subject:	Cold Storage Vessel as specified in Drawing No. 57.32.17634/8210

Material:	15 Mo 3
Operating period:	1 year
Operating temp.:	285^{o}C
Operating pressure:	Design 85 bar
Medium:	Sodium

Prepared by:	Dipl.-Ing. Loog
Department:	Materials Mechanics and Metallurgy
No. of pages:	15
Annexes:	Annex 0, pp.1-3; Annex 1, pp.1; Annex 2, pp.1-8; Annex 3, pp.1; Figs. 1 - 32; Annex 4, pp.1-2; Annex 5, pp.1-2; Annex 6, pp.1

2/029 9.78

0. Summary

Leakages had occurred several times in the weld area of the cold sodium storage vessel of a solar power plant. The cause of the damage was to be determined by means of a detailed examination of two crack areas at the manhole stud and at a baffle plate at the bottom of the container.

The following points were established:

- The applied material including the filler material fulfils the requirements in all inspected mechanical, technological and chemical values.
- The structural condition of the base material and the welded joint is normal.
- The material is susceptible to temper embrittlement.
- A sodium sample taken from the vessel was of reactor quality and did not exhibit any detrimental impurities at all.
- The investigated cracks exhibited the features of damage due to stress corrosion cracking both in the metallographic and fractographic findings. In all cases, the cracks originated from notches such as smaller welding flaws or the structure of the weld surface on the side in contact with sodium.
- No foreign materials, which could have caused stress corrosion cracking, were found on the parts supplied for the examination.
- Simulation tests in hot caustic soda produced the same type of fracture as that in the damage areas.
- Crack formations were only observed in that area of welding seams coming into contact with sodium. In addition, the position and direction of the cracks point to a connection with residual welding stresses, which, as is well known, can exceed the material yield point in dimensionally stable areas. The vessel had not be subjected to a stress relief heat treatment.

In order to cause stress corrosion cracking, one requires an appropriate initiating medium with a sufficiently high concentration, a sensitive material and, in addition, correspondingly high stresses. The following recommendations for the further procedure for the explanation of the damage repaire, and operation can be derived from the results of the examination:

- As the examination did not indicate any components which can cause stress corrosion cracking in the operating medium, the operating records should be checked as regards this point, and during subsequent operation care should be taken that no media which can cause the observed type of crack can enter the loop. According to present knowledge, these are alkaline and weak-acid oxidizing solutions, vapours and saline solutions.

- The applied material 15 Mo 3 has been successfully used as structural steel for pressure vessels and boilers for many years. On the basis of its composition, however, it cannot be termed as being resistant to cracking in caustic solutions. The operating loads including the residual stresses should therefore be kept as low as possible.

- The design of the baffle plate, which is permanently welded to the vessel on the base of the casing, implies high residual stresses after welding due to its inherent stability. In addition, these residual stresses are increased by the locally applicable stress concentration factor at notches - in particular at inaccessible points, which cannot be adequately levelled by grinding. It is therefore necessary to ensure smooth, notch-free material surfaces, particularly on the base of the casing.
  After the repair work,the residual weld stresses should be eliminated by means of stress relief heat treatment.

1. Information on the examination and the task

After a short operating period, the cold sodium storage vessel described above exhibited a leakage point in the area of the web welding points of baffle plates, positioned underneath the sodium inlet pipes (Annex 0, Page 1). The DFVLR report (Dr. Bucher) and Annex 0, Page 3 give further details on this and further defects, and on the repair measures performed for their elimination. After the occurrence of the latest defect, the TÜV Rheinland, Cologne was commissioned with the assessment of the final repair of the vessel and with the examinations for the clarification of the cause of the damage.

The following parts were supplied to the Institute for Materials Testing and Chemistry for the execution of the damage examinations:

- 2 web welding seams (SN 4) with the vessel casing sections which were still attached to them after the above repair work (Samples 1 and 2, Annex 0, Page 2). Please refer to Figs. 1 and 3 for a survey of the delivery condition.
- The entire welding area of stud No. 2 (see Annex 0, Page 1; please refer to Fig. 9 for an overview of the delivery condition and the condition after the magnetic particle test). A wedge-shaped section with two cracks had been cut out of the stud weld (Sample 3, Annex 0, Page 2).

Furthermore, the following parts were delivered for examination from other sections of the vessel due to detected or suspected damages, or for inspection of the material condition.

- 2 segments of the manhole stud welding seam (SN 41/1), on the inside of which magnetic particle indications had been detected at right angles to the welding seam (Figs. 7 and 8) (Samples 4 and 5).
- 2 pipe sections from the sodium inlet line, materials 15 Mo 3 and X 10 CrNiTi 189, which were to be subjected to examinations for thermo-shock cracks (Samples 6 and 7). These samples did not exhibit any indications during the surface crack test and are therefore not referred to again.
- 1 section from the vessel circumferential weld (SN 1/3) (Sample 8).

2. Tests performed and results

2.1 Determination of the damage structure

2.1.1 Surface crack test

The results of the surface crack tests performed on all delivered parts are listed in Annex 1.

The following summary was obtained:

- The stud weld exhibits 6 transverse cracks in the weld metal, some of which continue into the base material of the vessel (Figs. 9 and 11).
- The web welding seams exhibit undercuts and end crater cracks (Figs. 2 and 4). In one case, there is a transverse crack reaching into the base material of the web plate (arrow in Fig. 4).
- The segments of the manhole welding seam exhibit transverse cracks in the root area and longitudinal indications in the weld interface (Figs. 7 and 8).

2.1.2 Ultrasonic test

Samples 1,2 and 3 were subjected to a complete ultrasonic test to obtain information on the location and extent of the damage for the subsequent tests. The largest indications of samples 1 and 2 are drawn into Figs. 2 and 4. The detected defects are always in the weld area. The findings for Sample 3 are presented in Figs. 11 and 12 with the magnetic particle indications.

2.1.3 Radiographic inspection

The radiographic inspection of Samples 1,2 and 3 shows that the crack indications are finely branched in the base material and that some of them run on several planes in the material (Figs. 12a and 12b).

2.1.4 Metallographic inspection and hardness test

The results of the nine investigated microsections are listed in detail in Annex 2, Pages 1 - 8.

The following summary results:

- In all cases, the microstructural arrangement was normal for the specified materials.
- There were smaller welding defects (pores and fine slag) in three microsections. These would have been termed negligible in the evaluation of non-destructive test results.
- In the microsections, the cracks are mainly at right angles to the welding seam. The course of the crack is essentially transcrystalline in the weld metal and intercrystalline in the base material (Figs. 15a and 15b). The transcrystalline fractions in the base material are generally near perlite grains. The form of the cracks points to stress corrosion cracking and is similar to that detected by Interatom during the examination of a web crack.

2.1.5 Examination of fracture surfaces

In Samples 1 (web weld), 2 (stud weld) and 3 (manhole weld). the cracks at right angles to the welding seams were broken open. The examination shows that the cracks are always connected with the radius of influence of welding seams.

The course of the crack is primarily intercrystalline in the base material (Figs. 18 and 19) while the weld metal mainly exhibits transcrystalline fracture with clear intercrystalline fractions (Figs. 20 and 21).

The arrangement of the fractured surfaces therefore confirms the result of the metallographic examination (stress corrosion cracking). A qualitative radiographic analysis of the fractured surfaces, which was consequently performed using the energy dispersive analysis of X-rays, did not indicate any media causing stress corrosion cracking. Only sodium was detected in each case.

The residual forced fracture, which was effected at low temperatures in the laboratory (cooling in liquid nitrogen) consisted of a pure cleavage fracture in each case (Figs. 22 and 23) , which clearly differs from the operational fracture presented in Figs. 20 and 21.

The results of the fractured surface examinations are listed in detail in Annex 3.

2.2 Inspection of the applied materials

2.2.1 Mechanical tests

One tensile strength sample from the vessel circumferential weld (sample 8) taken across the welding seam was tested at room temperature, and a further sample from the base material at operating temperature (285°C). In addition, an a_K-T-curve was recorded in each case for the base material and the weld interface (coarse grained zone). The toughness of the base material in the damage zone was determined parallel to the welding seam of web 1 by means of two U-notch impact samples.

The results (see Annex 4) exhibited mechanical quality values, which in any case fulfilled the requirements imposed on the applied material 15 Mo 3 and, in some cases, were considerably better than the values specified in DIN 17155:

- The notch impact strength determined for the U-notch sample at room temperature is approximately 50 % better than the requirement imposed on the base material.
- The transition temperature for the base material, determined as the mean value of the low and high passes, is around + 24°C for V-notch-samples (Annex 4, Page 2).
- The transition temperature for the heat affected zone is around + 5°C for V-notch-samples (only 4 samples were tested because of the limited material supply).
- The high temperature yield point of the base material is 20 % better than the requirements at operating temperature.
- The welded joint inspected using a sample from the circumferential weld also fulfils the requirements.

2.2.2 Chemical analyses

The analyses of 2 base material and 5 weld metal samples indicate a material composition corresponding to that of the planned 15 Mo 3 including the relevant weld metal (Annex 5). There is therefore no mistaking of materials. The analysis of the sodium (Annex 5, Page 2) showed that its quality meets the requirements for (doubly purified) reactor sodium[1]. Indications for detrimental impurities were not detected.

2.3 Supplementary examinations to determine the cause of the damage

In principle, the mechanisms "liquid metal embrittlement" and "stress corrosion cracking" (caustic embrittlement) come into question as the cause of the observed intercrystalline crack formation, and, for the transcrystalline possibly also hydrogen-induced cathodic stress corrosion cracking.

Of the causes mentioned above, liquid metal embrittlement was excluded from the very beginning, as, according to all previous experience, it does not occur in the system iron/ sodium[2] and could not be explained from the metal physics aspect.

With reference to the remaining possibilities, the following supplementary examinations were performed as agreed on by the expert group in December 1982:

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1) Atomics International : Division of North American Aviation Inc.: NAA-SR-11805, February 1966

2) Gmelin "Iron and Sodium" Page 1809

2.3.1 Auger analysis

The purpose of this analysis was to examine whether clustering of certain elements, in particular phosphorus, which can cause intercrystalline fracture because of temper embrittlement is present at the grain boundaries. Two rods (Ø 3.0 x 30 mm length) were manufactured from the vessel circumferential weld (Sample 8) parallel to the welding seam in such a way that the fusion line was exactly along the centre of these rods and that, as a result, the weld metal and heat affected zone and, if necessary, slight fractions of the unaffected base material could be simultaneously inspected. On breaking the samples in the vacuum of the Auger apparatus, it was clear that no intercrystalline fracture had occured, i.e. no temper embrittlement was present, and hence it was not possible to verify any grain boundary deposits.

A random examination of the fracture surface produced in this way did not indicate any phosphorus deposits at all. Such deposits were not to be expected, due to the Low P-contents of the applied materials (see chemical analysis Annex 5, Page 1).

2.3.2 Stress analysis

Using residual stress measurements in the casing zone of the stud welding seam, peak values of up to 400 N/mm^2 were measured on the inside of the vessel opposite to the buffer welding seam. This results in stresses which exceed the determined yield point (see Point 2.2.1). A special report (No. SB 249/82) was compiled on this topic.

2.3.3 Tensile tests in caustic soda

Several tensile strength samples were manufactured from the stud welding seam in accordance with the diagram in Annex 6 (top). Some of these had to be excluded because of preliminary damage, which was not detected during the non-destructive test. Of the remaining 7, 4 were tested in 50%-caustic soda solution at $80^{\circ}C$ and at diverse stresses exceeding the yield point which was determined using a further sample.

One sample was provided with an 0.5 mm deep V-notch.

For comparative purposes, one sample was placed in calcium nitrate, which is specified as test solution for the test for intercrystalline stress corrosion cracking in SEP 1861-82.

None of the samples tested in caustic soda exhibited an attack as a result of stress corrosion cracking within 100 h. The tests were therefore terminated.

The comparative sample in calcium nitrate fractured after approximately 50 h and exhibited intergranular fracture in the edge zone and ductile fracture in the sample core.

2.3.4 Bending tests under caustic soda

As the tests described in 2.3.3 were not successful as regards the production of fracture surfaces, the testing method for intercrystalline crack formation according to SEP 1861-82 was modified with reference to the medium and the sample-taking. Caustic soda was used as medium and the sample was taken in the longitudinal weld direction, in order to force crack formation in cross direction (see Annex 6). The samples were taken from the material of the non-annealed work sample for repair weldings.

For the test, the samples were prestressed to 4 different "a-distances" (cf. Annex 6). The samples were simultaneously introduced into the 50 % caustic soda, which had a temperature of 80^{o}C. After 120 h test duration, all samples exhibited commencing crack formation. On the exposed fracture surfaces, one could see that the crack depth decreased with decreasing prestressing and that the base material was more susceptible than the weld metal. The cracks are metallographically and fractographically documented in Figs. 27-30. It is evident that the course of the cracks in the base material is mainly intercrystalline and that the course of those in the weld metal is mainly transcrystalline. The transcrystalline fractions in the base material are frequently found near perlite grains. Both this observation and the microstructure of the fracture surface present a picture, which is, for the most part, similar to the damage case.

2.3.5 Bending tests under hydrogen loading

Due to the observed transcrystalline fracture fractions, the purpose of the tests described in the following was to produce fracture surfaces, which are caused by the affect of atomic hydrogen. The test assembly was the same as that in 2.3.4, but the samples were prepared with an 0.5 mm deep V-notch at the point of greatest bending in order to shorten the test duration.

Acetic acid was added to distilled water until the value pH = 5 was reached. This was used as the medium, through which H_2S was passed at room temperature until saturation occurred. The two samples were prestressed to such an extent that a commencing deformation could be observed in the base of the notch under the stereo microscope.

One sample was withdrawn after 3 hours and the other after a 20h-test duration. Cracks of varying depths were obvious:

3 h- sample : 1.0 mm

20 h- sample : 2.3 mm

The crack depth in the weld metal was considerably larger than in the base material.

Figs. 31 and 32 present the transcrystalline fracture surfaces which were obtained in the base material and the weld metal. One can see, that these clearly differ from those produced in caustic soda solution and also from those which were present in the damage case.

3. Conclusions and evaluation

The examination supplied the following results:

- The examined cracks preferably run at right angles to the welding seam and stretch into the unaffected base material. The point of origin in each case is either a small, generally unimportant welding flaw or a notch on the weld surface of the side in contact with sodium.
- Some of the cracks are branched. Their course is primarily intercrystalline in the base material and almost always transcrystalline in the weld metal.
- With the exception of sodium, absolutely no foreign materials, which could have caused stress corrosion cracking, were detected on the fracture surfaces.
- The applied material including the weld metal meets the requirements of DIN 17155 as regards all tested mechanical, technological and chemical values.
- The structural condition of the base material and the weld joint is normal.
- The material was tested for temper embrittlement. Susceptibility was not established.
- The analysis of the sodium indicated that we were dealing with very pure reactor sodium. No detrimental impurities were detected which could have been connected with the crack formations in the material.

As, according to current knowledge, it is possible to exclude any tendency of the material to liquid metal embrittlement in the presence of liquid sodium under the specified operating conditions, the observed damage can only be explained as damage due to stress corrosion cracking. Furthermore, as the examination did not indicate the presence of a medium initiating stress corrosion cracking, it is reasonable to assume that the damage was caused by caustic soda. It was, however, impossible to prove this under the given conditions and with the acknowledged analytical methods. This, however, is not surprising, as, in the case of stress corrosion cracking, it is often impossible to verify the medium causing the damage and one must indirectly deduce this medium from the operating conditions or disturbances of the same.

The simulation tests performed in caustic soda presented the same fracture structure as that on the damage fracture surfaces.

Even if it is impossible to positively identify which medium was involved in the determined type of damage, the residual stresses due to design and manufacture which were present in the damage area and the effects of which were increased by welding flaws and notches on the weld surface were,in any case,responsible for the damage.

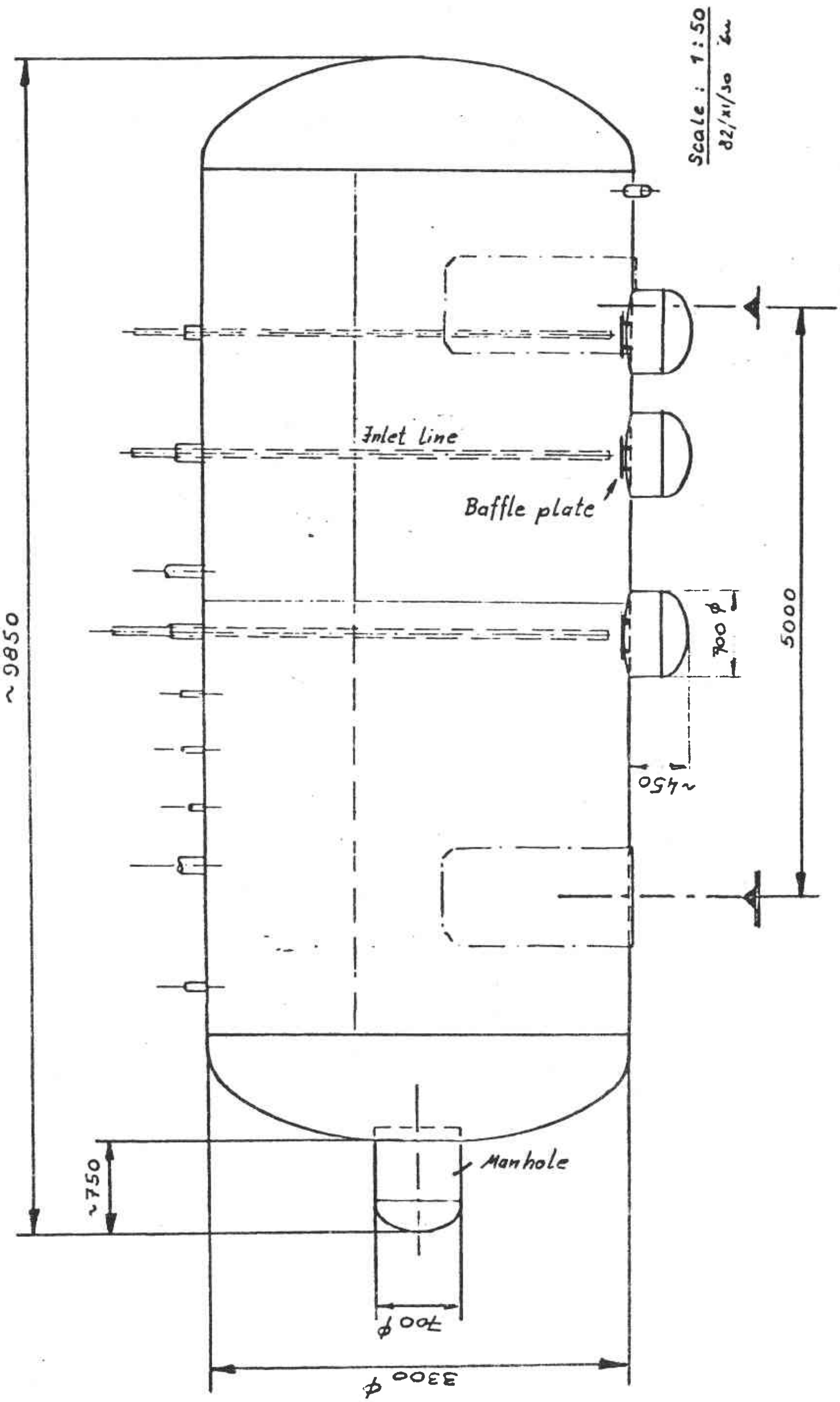
The Inspectors

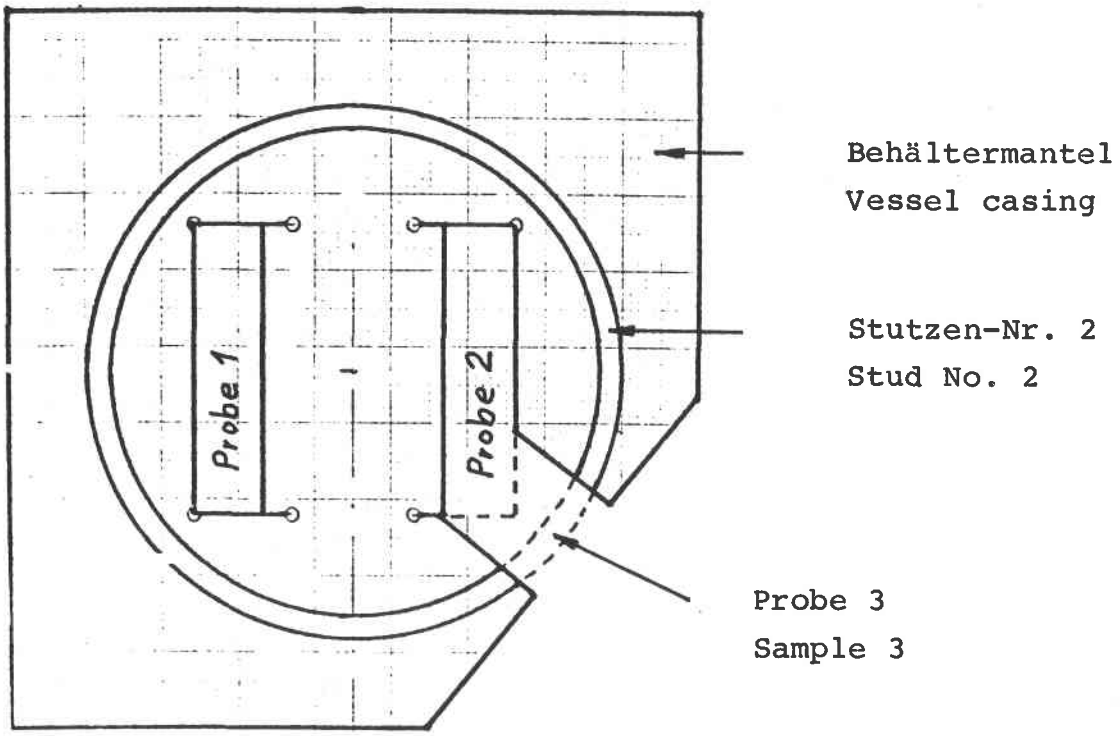
Kaufmann D. Loog

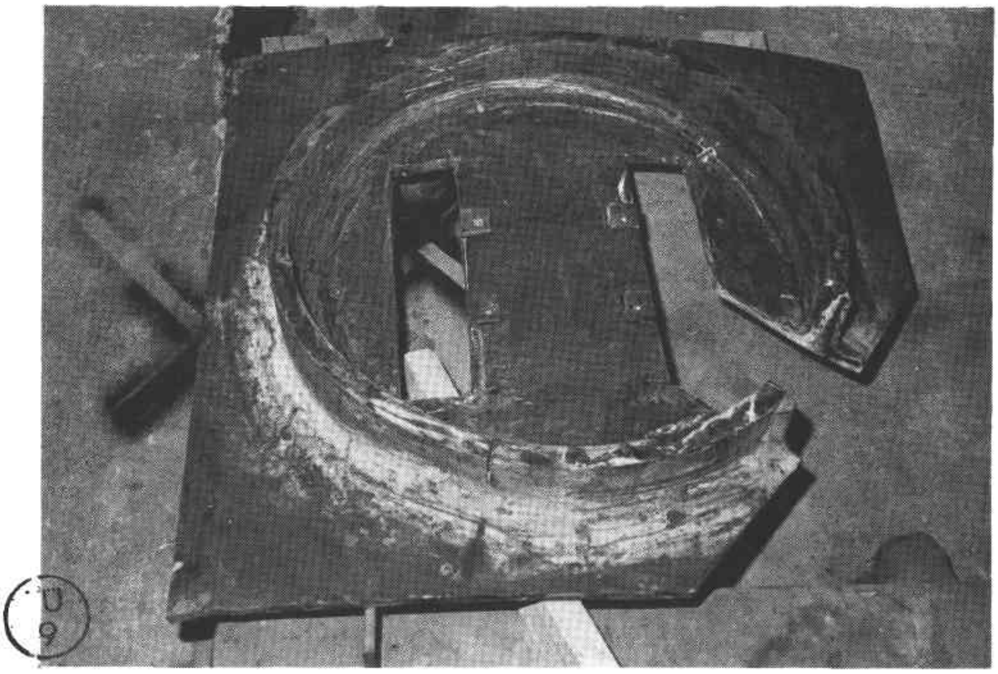
(Dr. Kaufmann) (Dipl.-Ing. Loog)

Annex 0, Page 1

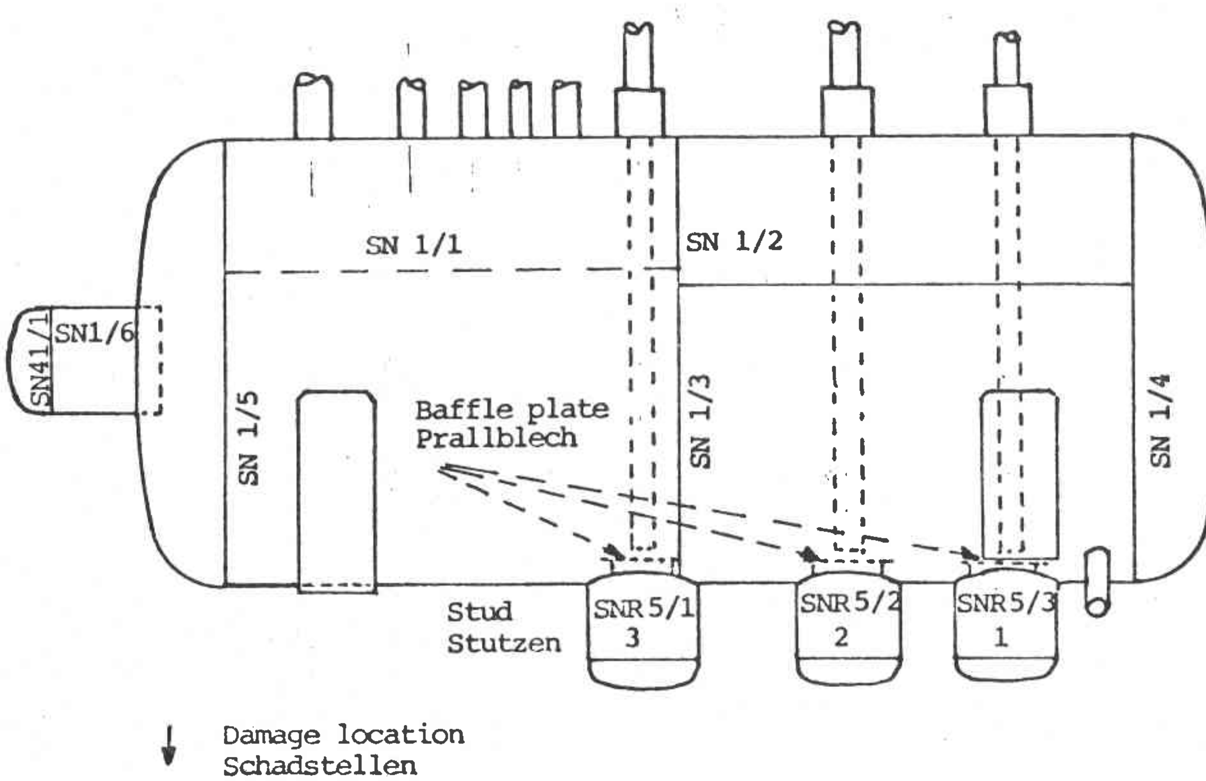
W323/82

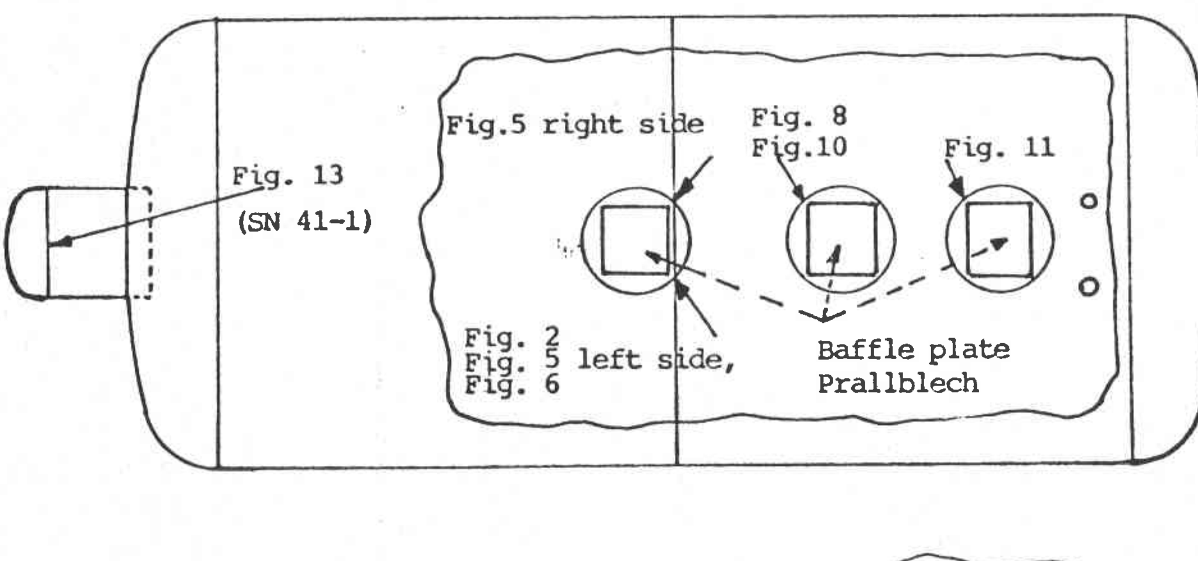






Supplied vessel section with separated stud





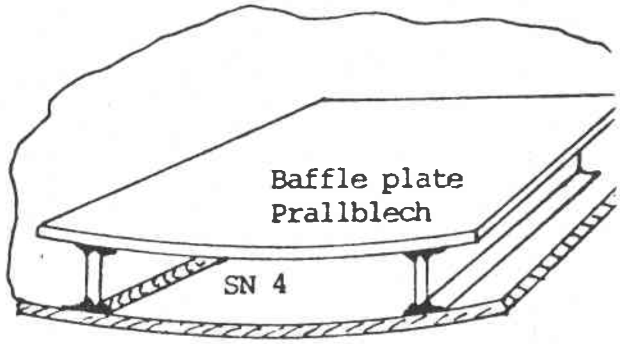


Fig. 7.3/12

Fig. 7.2/
7.4

SN = Welding Seam
SNR = Repair Welding Seam

Annex 1

Results of the surface crack test

Identification	Test method	Results
Web weld Web 1 (Sample 1)	Magnetic particle	In the delivery condition, weld spatters on and beside the welding seam (Fig. 1). Undercuts and a crack indication at the ground end crater can be seen in the test condition(Fig.2).
Web weld Web 2 (Sample 2)	Magnetic particle	The illustration presents the condition of Sample 2 after a crack between the boreholes had been exposed at a depth of 27 cm for a fast surface fracture inspection. The scale on the unground weld indicates that the crack obviously originated from a contact point for the welding process. In the test condition, there are numerous weld spatters on and beside the weld. Undercuts are also evident.
Stud section (Sample 3)	Magnetic particle	2 crack indications on the inside of the stud, one of which is the continuation of a crack boring (Fig.5) , although it does not originate from this; 1 flaw indication on the outside of the stud (Fig. 6). Crack, Fig. 5 right, is the rear side of crack, Fig. 6.
2 Manhole weld segments	Magnetic particle	Several crack indications both longitudinal and at right angles to the welding seam (Figs. 7 and 8) .
2 sodium inlet lines	Magnetic particle and dye penetration test	The pipes were cut through longitudinally and tested inside and outside. No indications were found (no illustration).
Stud weld (see Fig. in Annex 0)	Magnetic particle	4 crack indications in the weld metal on the inside of the stud (Fig. 9) and one along the weld in the base material on the casing side (Fig. 10). Crack locations : + 75, + 460, + 735, - 125 measured from the zero point.

Results of the metallographic examinations and hardness tests

Sample No.	Microsection No.	Point of removal	Results
1.	1.1	Web 1, transverse microsection (location see Fig. 2)	The web plate is thoroughly fused, but exhibits an approximately 0.8 mm long slag inclusion on the unground side (no illustration). The maximum measured hardness is around 232 HV 10 in the heat affected zone. See Annex 2, Page 3 for the hardness profile and macro-photo.
1.	1.2	Web 1, Longitudinal microsection (location see Fig. 2)	The microsection is located in a part of the sample with 2 ultrasonic indications. However, no defect could be detected in the microsection itself (no illustration).
2.	2.1	Web 2, transverse microsection (location see Fig. 4)	The microsection was taken across an ultrasonic indication. There were 2 cases of lack of side wall fusion (max. 2.5 mm long), one slag inclusion and an 0.3 mm long crack in the weld interface. The max. hardness was around 243 HV 10 in the heat affected zone (Annex 2, Page 4)
3.	3.1	Stud longitudinal microsection (location see Fig. 13)	The microsection was taken through the crack in the weld metal presented in Fig. 5, left. The 2 cracks shown in Fig.14 appeared in the weld metal, one of these continued into the base material. In Figs. 15a and b one can see that the faults in the weld metal and in the base material are both inter- and transcrystalline.
3.	3.2	Stud transverse microsection (location see Fig. 13)	The weld buildup of the stud weld is shown in Annex 2, Page 5 . It is obvious that, apart from some small pores and an approx. 1 mm long interrun fusion defect between buffer and stud weld, no cracks are present. The determined hardness values are listed in Annex 2, Page 5 .

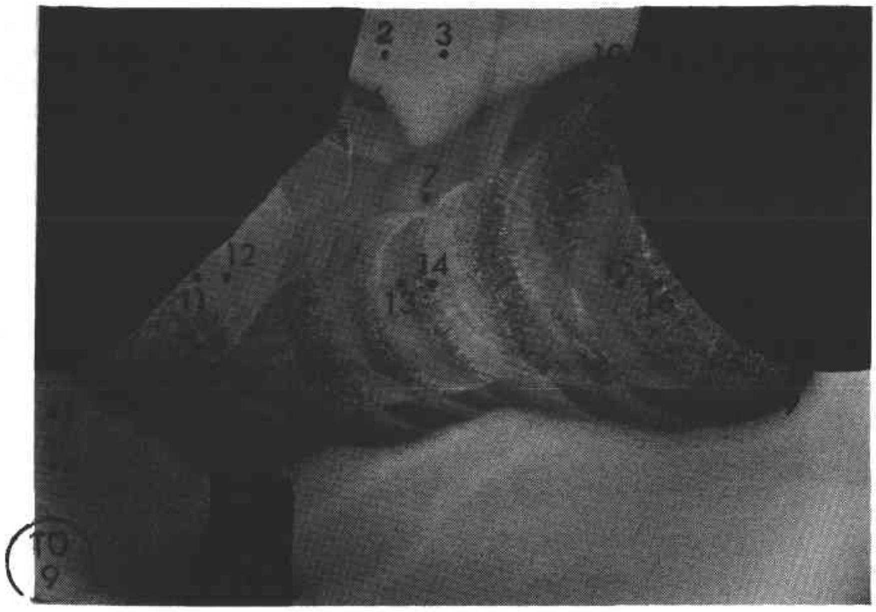
Continuation

Sample No.	Microsection No.	Point of removal	Results
4.	4.1	Manhole transverse microsection, location Figs.7+8	There was a crack with a mainly inter-crystalline course in a decarburized zone beside the root pass. The crack appearance was similar to that in Fig. 15. A survey photo and the determined hardness values are listed in Annex 2, Page 6.
4.	4.2	Manhole longitudinal microsection, location Figs.7 + 8	A crack with a mainly transcrystalline course starts from a surface notch of the root welding. After approx. one third of the crack length, it passes through a pore in the weld metal. The crack is partially branched and approx. 6 mm long. Survey and detailed photos are presented in Figs. 15 c to 15 f.
6.	6.1	Inlet pipe ring micro-section ferritic	The examination did not indicate any crack formation (no illustration).
7.	7.1	Inlet pipe ring micro-section austenitic	The examination did not indicate any crack formation (no illustration).
8.	8.1	Circumfer-ential weld transverse microsection	No flaws were detected. The structural arrangements are listed in Annex 2, Page 7. The results of the hardness test on the transverse microsection and on the surface are listed in Annex 2, Page 8.

HÄRTEPRÜFUNG NACH VICKERS
an Schweißverbindungen

Prüf-Nr. W 323/8 2
Annex 2, Page 3

Sample No.: 1.1



Microsection 1.1 Scale 2,4:1

Testpoint	Loading: 98 N Hardness			
1	164			
2	175			
3	162			
4	150			
5	219			
6	199			
7	206			
8	196			
9	224			
10	218			
11	194			
12	197			
13	209			
14	192			
15	213			
16	213			

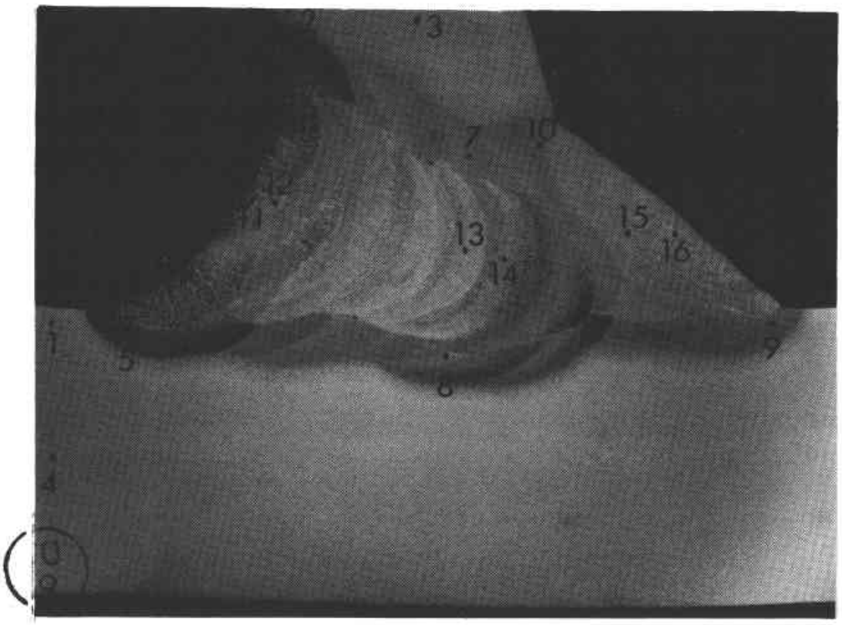
Schliff-Nr.				

HÄRTEPRÜFUNG NACH VICKERS
an Schweißverbindungen

Prüf-Nr. W 323/82
Annes 2, Page 4

TÜV RHEINLAND

Sample No.: 2.1



Microsection 2.1

Testpoint	Loading: 98 N Hardness			
1	165			
2	172			
3	163			
4	148			
5	243			
6	228			
7	183			
8	187			
9	219			
10	193			
11	230			
12	218			
13	183			
14	172			
15	191			
16	206			

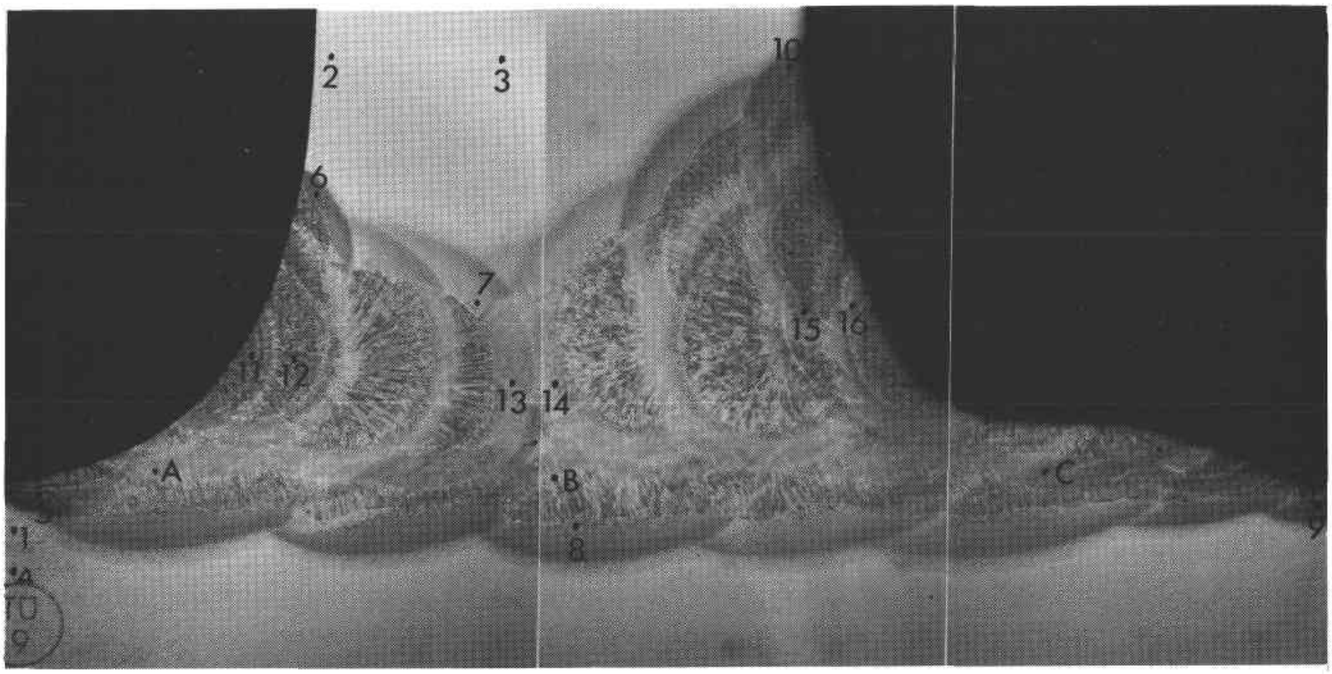
Schliff-Nr.				

HÄRTEPRÜFUNG NACH VICKERS
an Schweißverbindungen

Prüf-Nr. W 323/82
Annex 2, Page 5

TÜV RHEINLAND

Sample No.: 3.2



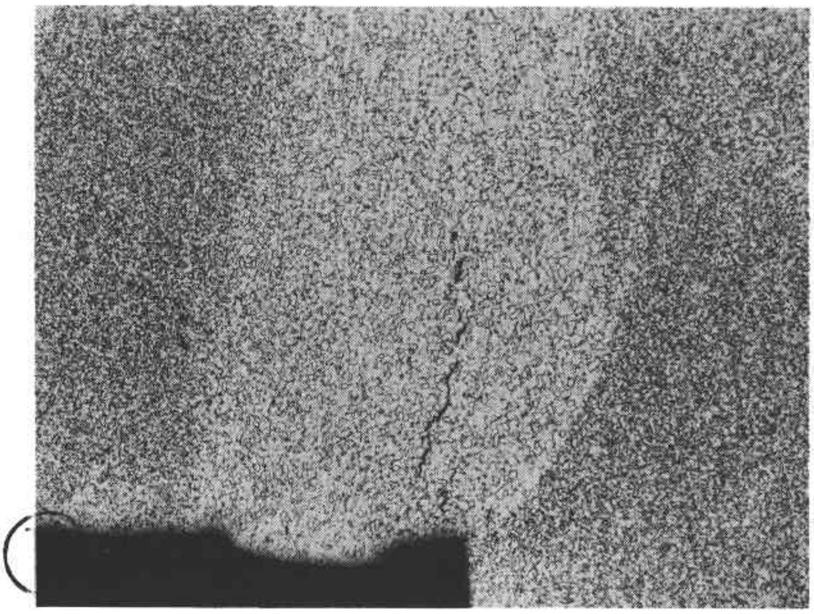
Testpoint	Loading: 98 N Hardness			
1	181	A	262	
2	170	B	243	
3	146	C	222	
4	153			
5	351			
6	274			
7	232			
8	285			
9	251			
10	264			
11	216			
12	235			
13	233			
14	227			
15	253			
16	264			

Schliff-Nr.				

HÄRTEPRÜFUNG NACH VICKERS
an Schweißverbindungen

Prüf-Nr. W 323/82
Annex 2, Page 6

Sample No.: 4.1



Microsection 4.1

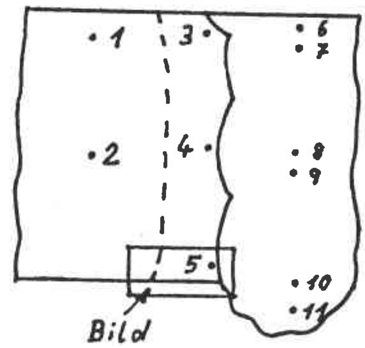


Fig.

Testpoint	Loading: 98 N Hardness			
1	186			
2	169			
3	218			
4	185			
5	165			
6	192			
7	198			
8	193			
9	206			
10	201			
11	183			
12				
13				
14				
15				
16				

Schliff-Nr.				

Institut für Materialprüfung und Chemie Werkstoffmechanik und Metallkunde	Cross section, circumferential welding, Sample 8.1	Annex 2, Page 7 Prüf-Nr. W 323/82

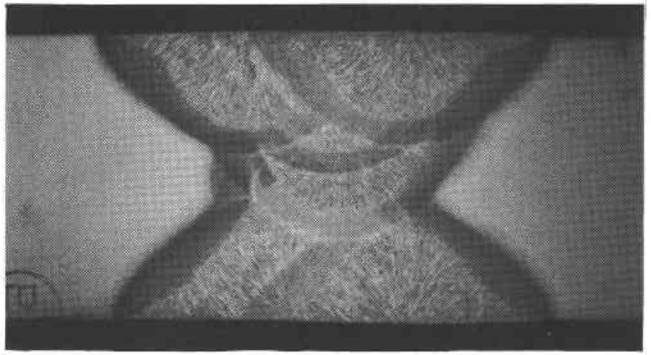
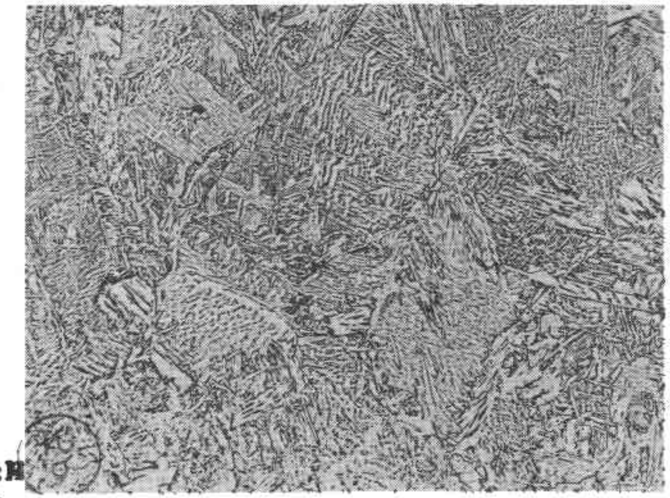


Fig.: I Macro structure

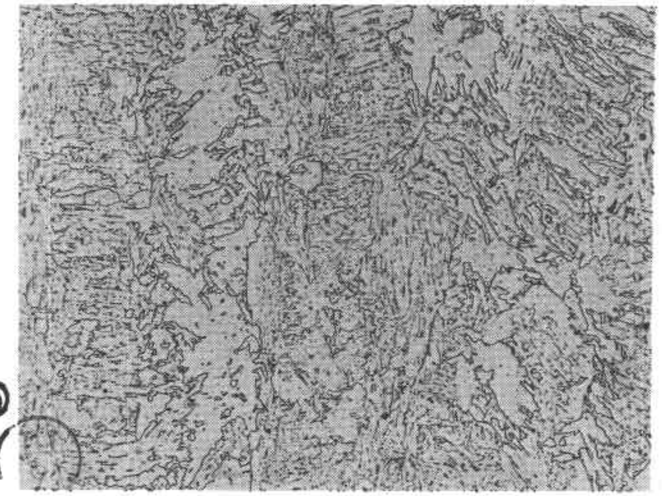
Etching: HNO_3

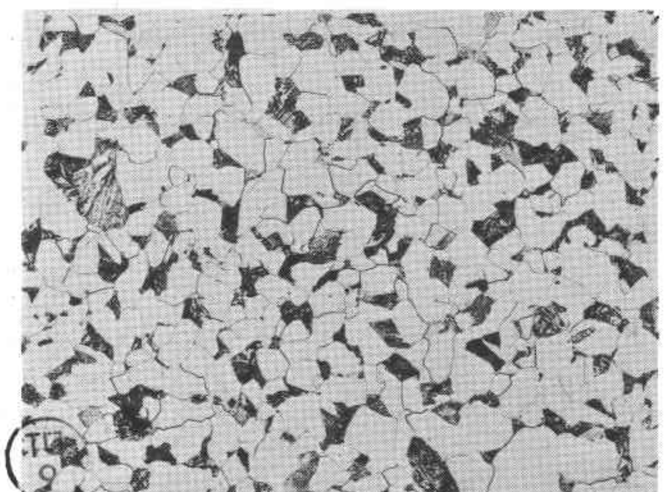
Micro structure, Scala: 200:1, Etching: H
HNO_3

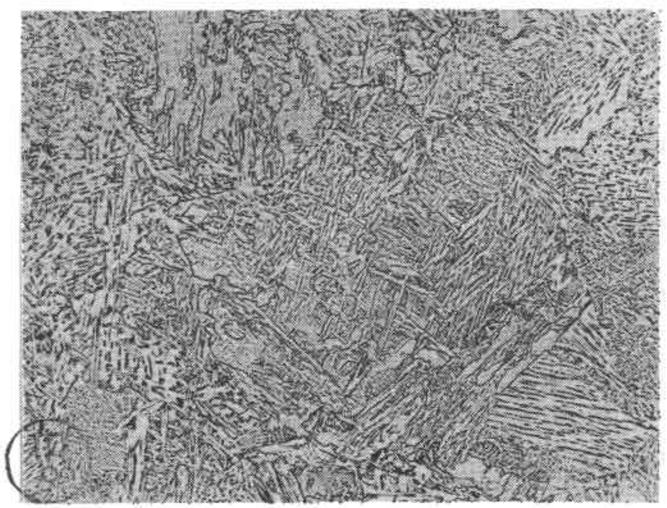
Material: 15 Mo 3



b







a

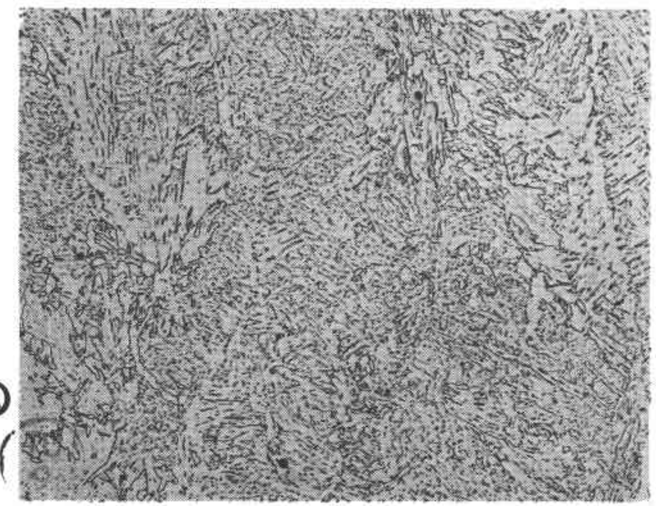


Fig.: II Base metal

Fig.: III Heat-affectedzone
a) = in the middle
b) = near surface

Fig.: IV Weld metal a)= in the middle
b)= near surface

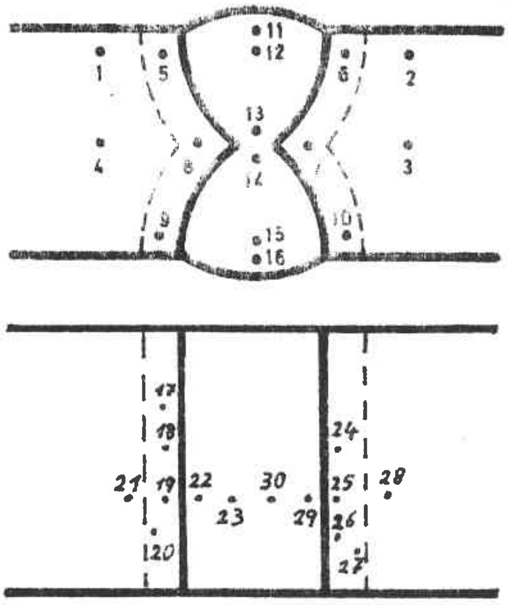
HÄRTEPRÜFUNG NACH VICKERS
an Schweißverbindungen

Prüf-Nr. W 323/82

Annex 2, Page 8

Sample No.: 8.1

Base metal 2 Base metal 1



cross-section

surface-section

Testpoint	Loading: 98 N Hardness			
1	168	17	227	
2	171	18	227	
3	149	19	227	
4	153	20	206	
5	242	21	167	
6	230	22	219	
7	210	23	219	
8	193	24	224	
9	230	25	218	
10	227	26	221	
11	207	27	178	
12	207	28	177	
13	203	29	216	
14	198	30	218	
15	207			
16	209			

Schliff-Nr.				

Annex 3

Results of the fracture surface examinations

Sample No.	Fracture surface No.	Point of removal	Results
1	B 1.1	Web 1 US-indication (Fig. 2)	The ultrasonic indication identified as "B 1.1" was exposed. This was a 2.5 mm long lack of fusion defect without access to the outside surface (no illustration).
2.	B 2.1	Web 2 bored crack in web plate	After separation of the material to the left and to the right of the boreholes, the sample was cooled in liquid nitrogen and the fracture surface was exposed. Figs. 16 and 17 present the fracture surface, and, as a comparison, a transverse microsection from the same sample. Figs. 18 - 23 show details from the base material, weld metal and laboratory fracture One can see that the fracture in the base material is essentially intercrystalline (Fig.19), while that in the weld metal is basically transcrystalline (Figs. 20 and 21). The laboratory fracture was a pure cleavage fracture.
3	B 3.1	Stud crack from microsection 3.1 (Fig.13)	After removal of the microsection 3.1, the remaining part of the crack was exposed. Fig. 24 presents the fracture surface. In order to facilitate orientation, the fusion lines were drawn in using the microsection picture and the fracture structure. The outlines of the damaged areas are marked with dotted lines. It is evident that the crack started from a pore (Fig. 24a) on the inside of the stud, which reaches to the surface of the weld, and that it has passed through approx. 75 % of the wall thickness in this case. As in sample "B 2.1", the weld metal and the adjacent base material zones were damaged. Figs. 25 and 26 were taken in the damaged part of the sample and show the interface between weld metal and base material. The fracture appearance therefore ressembles that of sample B 2.1.
4	B 4.1	Manhole transverse microsection (Fig.7)	After cooling in nitrogen, the root defect was broken open. A fracture surface similar to that in Sample B 3.1 was obtained (no illustration).

With the exception of sodium, absolutely no foreign materials were detected on any of the fracture surfaces.

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Impact Test — Notch: ISO-V and DVM

Sample No.	Dim. of spec. Width mm	Thickn. mm	Cross section cm²	Test temp. °C	Impact Energy J	Strength J/cm²	Position	Crystal. proportion %	Expansion mm	Remarks	
1	10,0	8,0	0,8	± 0	24	30	q	95	0,50	GW 1	(ISO-V)
2	10,0	8,0	0,8	± 0	28	35	q	95	0,55	GW 1	(ISO-V)
3	10,0	8,0	0,8	- 20	12	15	q	100	0,20	GW 1	(ISO-V)
4	10,0	8,0	0,8	- 20	12	15	q	100	0,25	GW 1	(ISO-V)
5	10,0	8,0	0,8	+ 40	62	78	q	50	1,20	GW 1	(ISO-V)
6	10,0	8,0	0,8	+ 40	68	85	q	30	1,30	GW 1	(ISO-V)
7	10,0	8,0	0,8	+ 80	84	105	q	0	1,60	GW 1	(ISO-V)
8	10,0	8,0	0,8	+ 80	88	110	q	0	1,60	GW 1	(ISO-V)
9	10,0	8,0	0,8	+120	80	100	q	0	1,60	GW 1	(ISO-V)
10	10,0	8,0	0,8	+120	82	103	q	0	1,60	GW 1	(ISO-V)
11	10,0	8,0	0,8	+ 60	76	95	q	0	1,45	GW 1	(ISO-V)
12	10,0	8,0	0,8	+ 60	82	103	q	0	1,55	GW 1	(ISO-V)
13	10,0	8,0	0,8	- 50	6	8	q	100	0,10	GW 1	(ISO-V)
14	10,0	8,0	0,8	+ 20	38	48	q	80	0,80	GW 1	(ISO-V)
15	10,0	8,0	0,8	+255	72	90	q	0	1,60	GW 1	(ISO-V)
16	10,0	8,0	0,8	+255	76	95	q	0	1,60	GW 1	(ISO-V)
U1	10,0	8,0	0,8	RT	60	75	PO-Ü	60	1,15	WEZ	(ISO-V)
U2	10,0	8,0	0,8	- 20	14	18	PO-Ü	95	0,25	WEZ	(ISO-V)
U3	10,0	8,0	0,8	+ 60	88	110	PO-Ü	0	1,65	WEZ	(ISO-V)
U4	10,0	8,0	0,8	+ 90	92	115	PO-Ü	0	1,7	WEZ	(ISO-V)
1.1	10,0	7,0	0,7	RT	63	90	q	-	--	Probe 1	(DVM)
1.2	10,0	7,0	0,7	RT	62	89	q	-	--	Probe 1	(DVM)
2.1	10,0	8,0	0,8	RT	64	80	q	50	1,30	GW 2	(ISO-V)
2.2	10,0	8,0	0,8	RT	64	80	q	50	1,25	GW 2	(ISO-V)
2.3	10,0	8,0	0,8	RT	62	78	q	50	1,25	GW 2	(ISO-V)
Requirements (DIN 17155 (1.59))						≧59	DVM				

Tensile Test

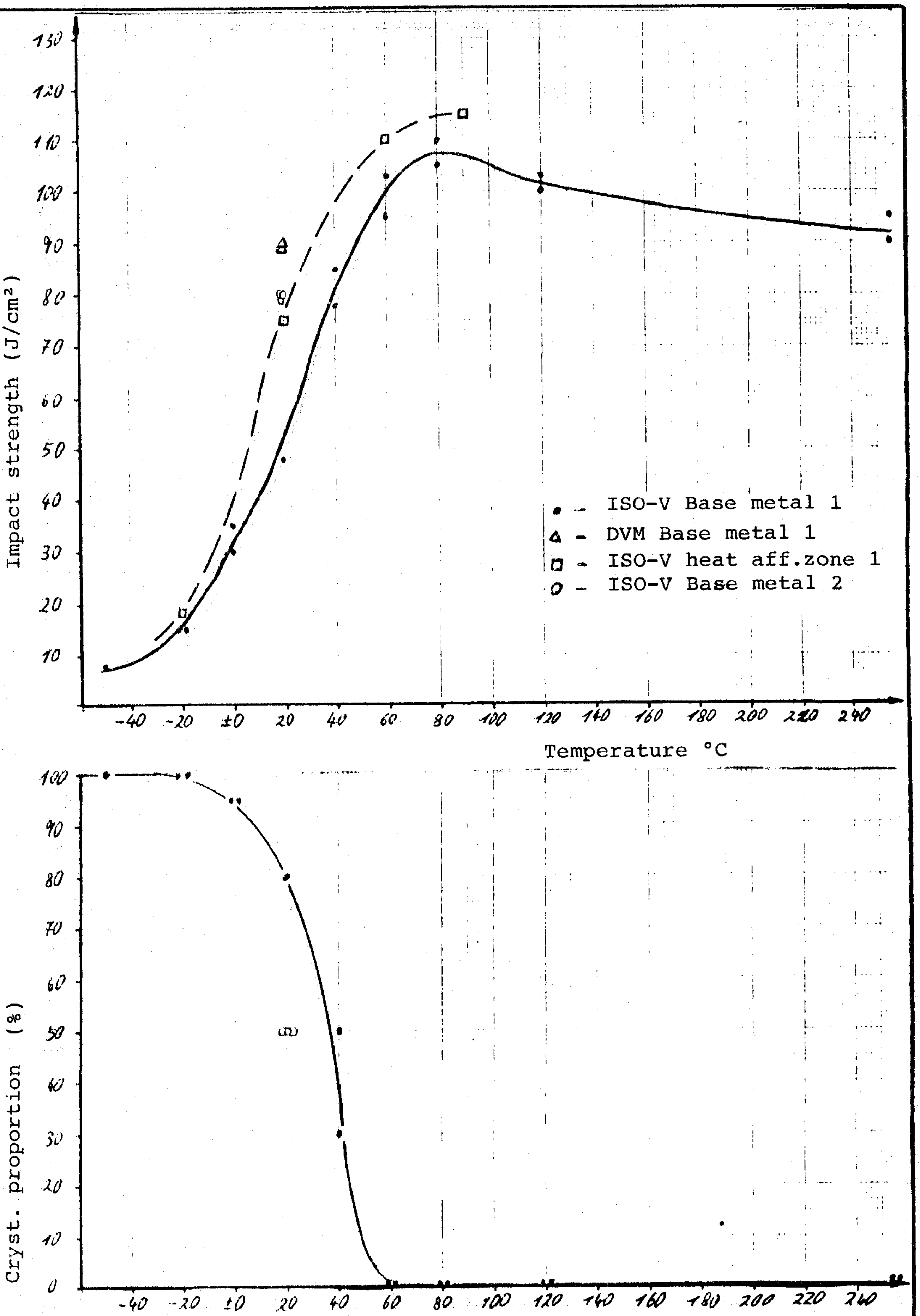
Sample No.	Dim. of spec Width mm	Thickn mm	Cross section mm²	Meas. Length mm	0,2 % N	Yield point N/mm²	1,0 % N	1,0 % N/mm²	Tensile strength N	Tensile strength N/mm²	Elong. %	Red. %	Fract. Loc.	Test temp. °C
G2	Ø	10,0	78,54	50	20600	262	-	-	47300	602	19,0	45	M	285
SG	25,0	15,7	392,5	25/50	147580	376	-	-	213900	545	- +	54	GW	RT
Requirements (DIN 17155 (1.59))					≧	265	-	-	430-	520	≧ 18	-	GW	RT
Requirements " " interpolated					≧	206	-	-	-	-	-	-	GW	285

"M" = middle of specimen

"GW" = Base material

"WEZ" = heat affectedzone

"+" = fracture out of used length



Abt.: 923	Tensile Test	Auftr.: W323/82
gez.: LOOG		Annex 4
Dat.: 8.12.82		Page 2

Element	Requirement GW	Base metal 1	Base metal 2	weld metal
C	0,12-0,20	0,180	0,185	0,080
Si	0,15-0,35	0,23	0,24	0,50
Mn	0,50-0,70	0,57	0,57	1,05
P	< 0,040	0,007	0,007	0,015
S	< 0,040	0,014	0,014	0,016
Cr	--	0,16	0,16	0,06
Mo	0,25-0,35	0,30	0,30	0,50
Ni	--	0,04	0,04	0,02
As	--	0,005	0,005	0,005
Sn	--	0,005	0,005	0,004
Cu	--	0,04	0,04	0,06
Co	--	< 0,01	< 0,01	< 0,01

The values were determined by means of X-ray analysis.
The analysis was repeated after 2 and 4 mm had been ground off.
The determined values were confirmed.

Sample		% Cr	% Mo
1	Web weld metal	0,04	0,19
3 a)	Buffer	0,05	0,45
b)	Stud weld metal	0,05	0,45
4 a)	Root weld metal	0,03	0,45
b)	Cover pass	0,03	0,43

The values were chemically determined.

<u>Sodium analysis</u>

K 49 mg/kg

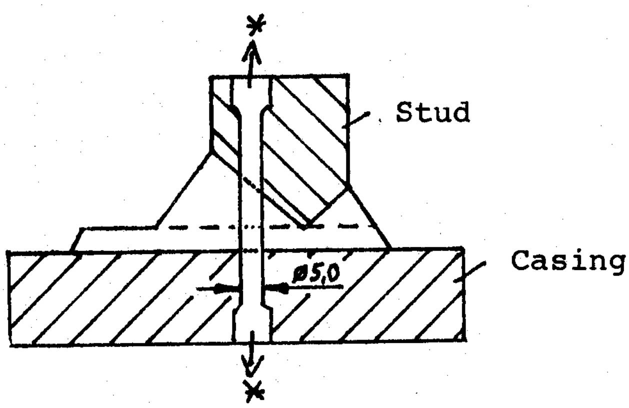
Mg 4 mg/kg

Ca 21 mg/kg

Annes 6

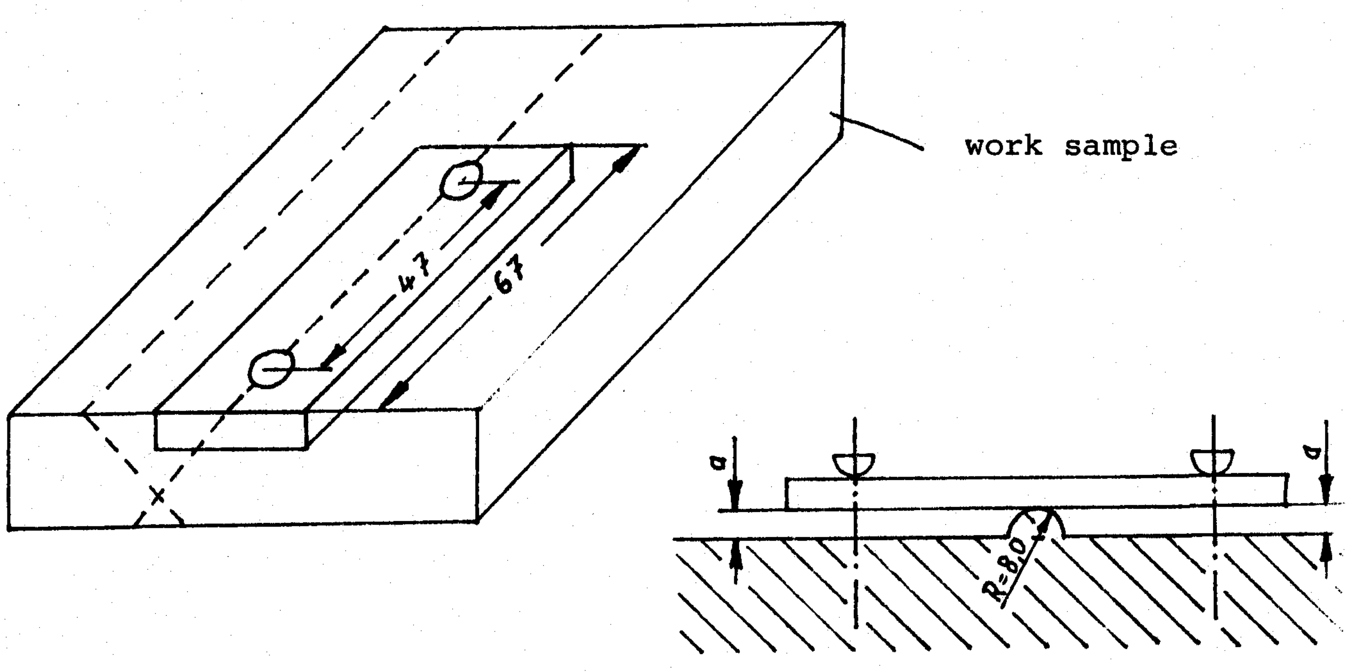
Sample preparations for corrosion testing

Tensile strength samples



* Elongation via welding

Jones-samples



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Prüf-Nr.: W 323/82

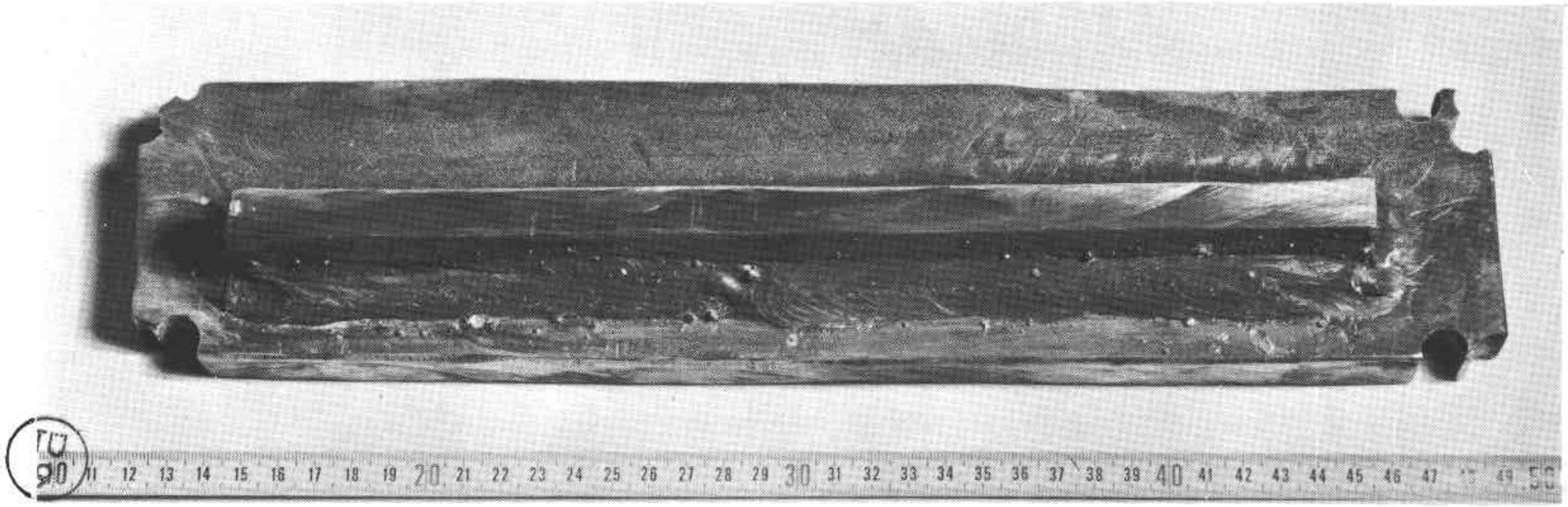

Fig. 1 Web No. 1 in the delivery condition (the back-up weld ist ground) approx. 1:2

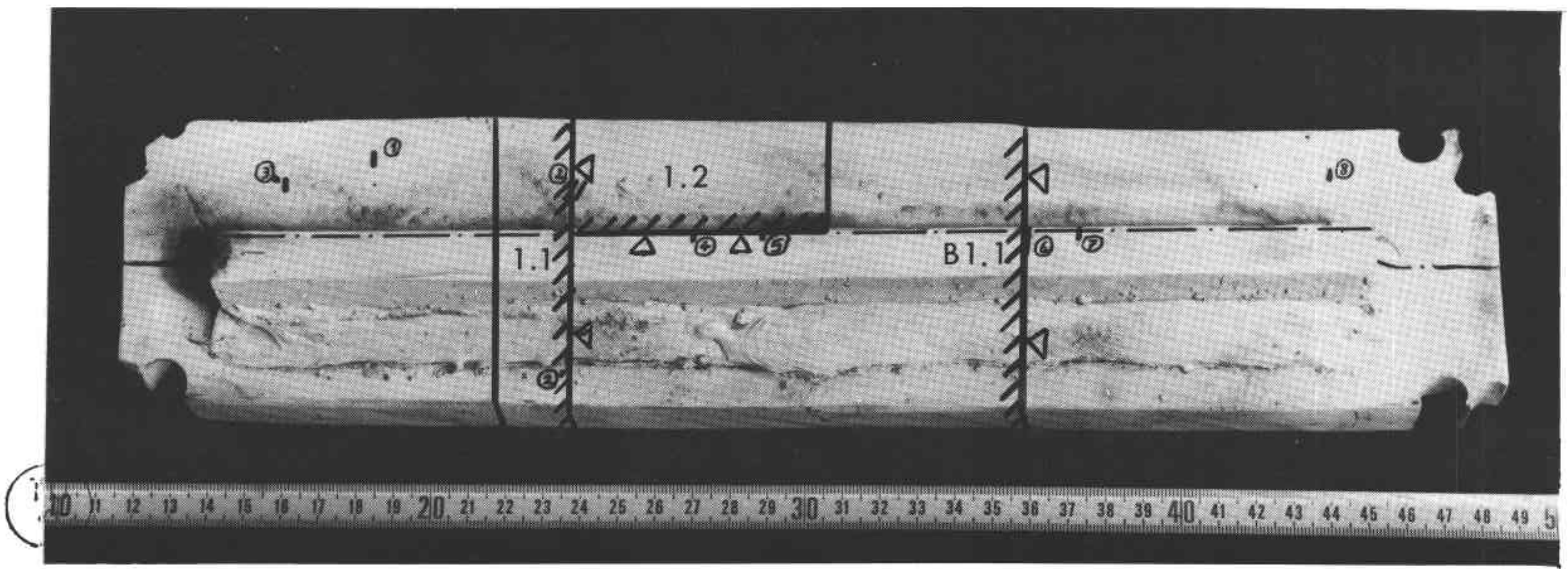

Fig. 2 Magnetic particle indications on Web No. 1 approx. 1:2
US-indications marked with I

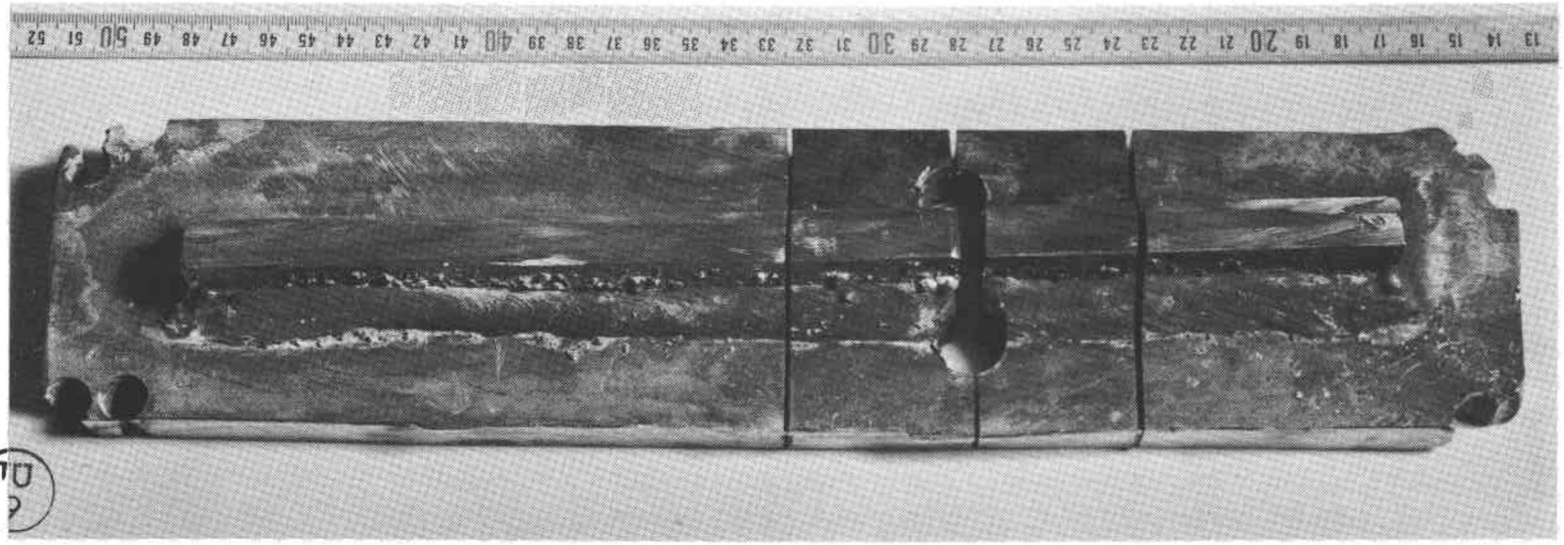

Fig. 3 Web No. 2 in the delivery condition (the back-up weld is ground) approx. 1:2

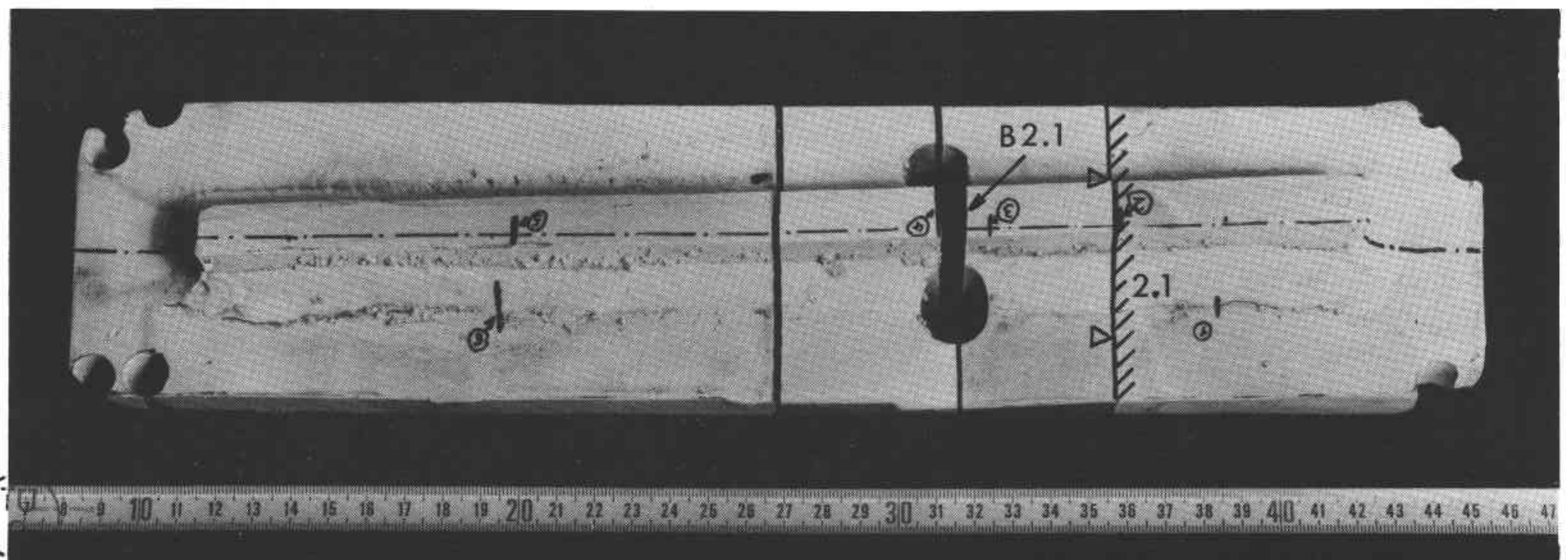

Fig. 4 Magnetic particle indications on Web No. 2 approx. 1:1

US-indications marked with I

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Prüf-Nr.: W 323/82

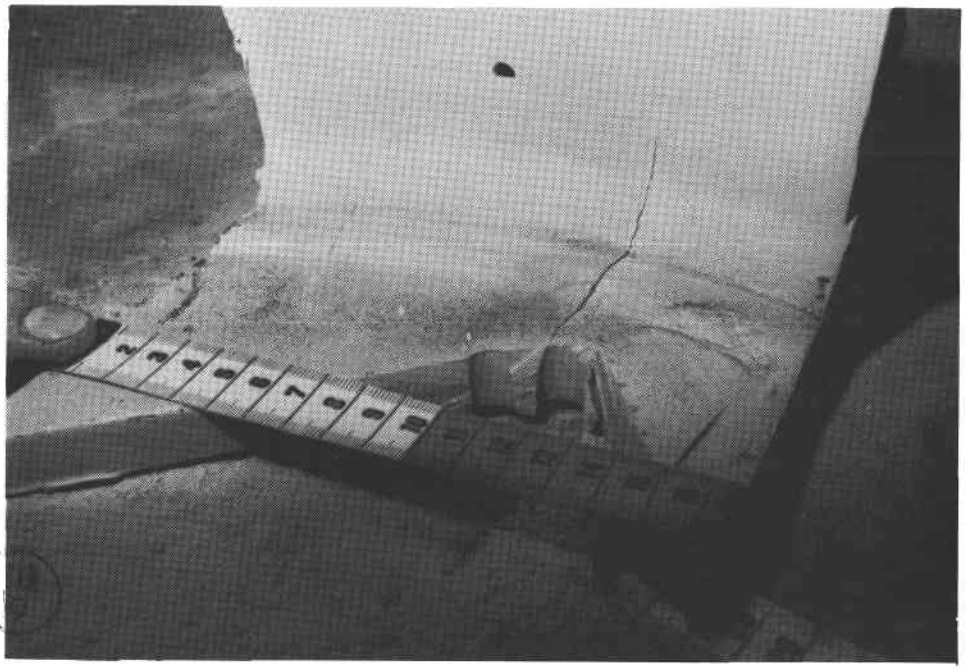


Fig. 5 Crack indications on the inside of the stud

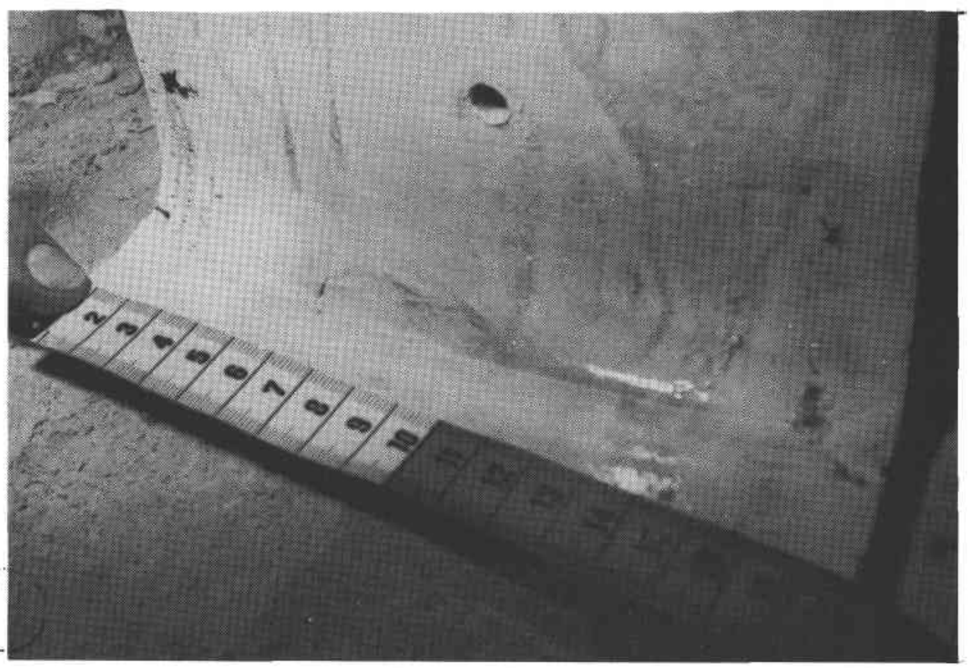
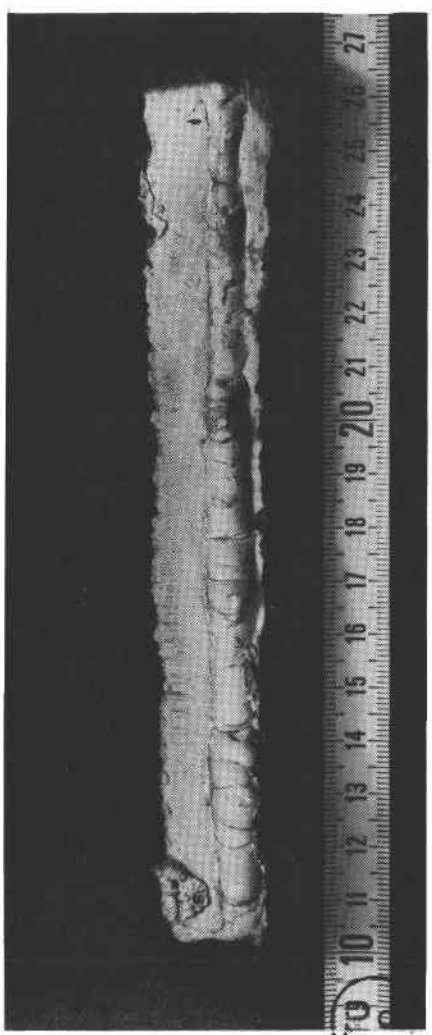
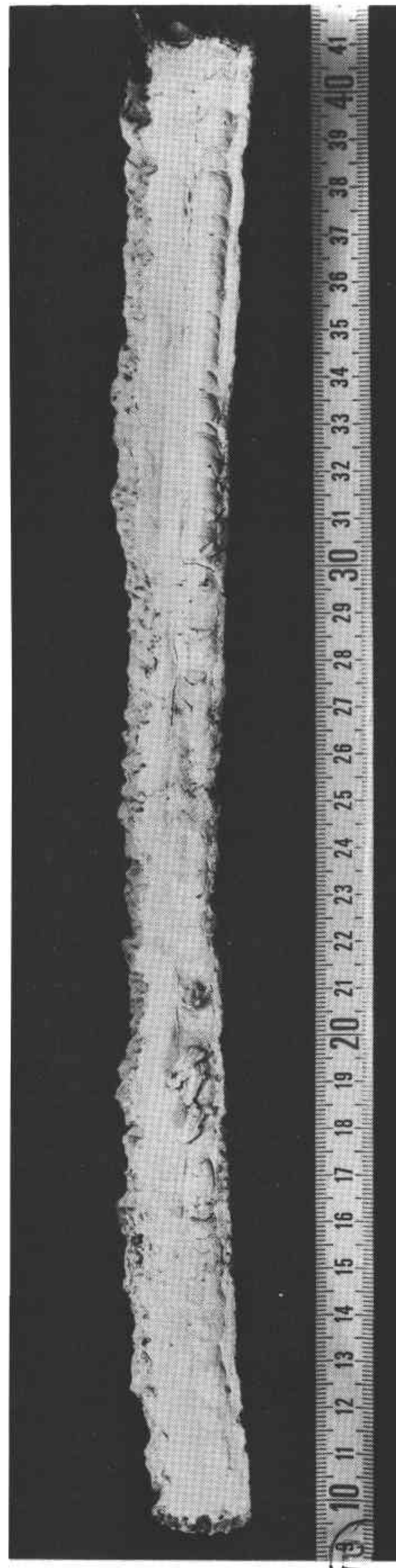


Fig. 6 Crack indications on the outside of the stud



1:1,7



1:1,7

Figs. 7+8 Crack indications in the manhole welds

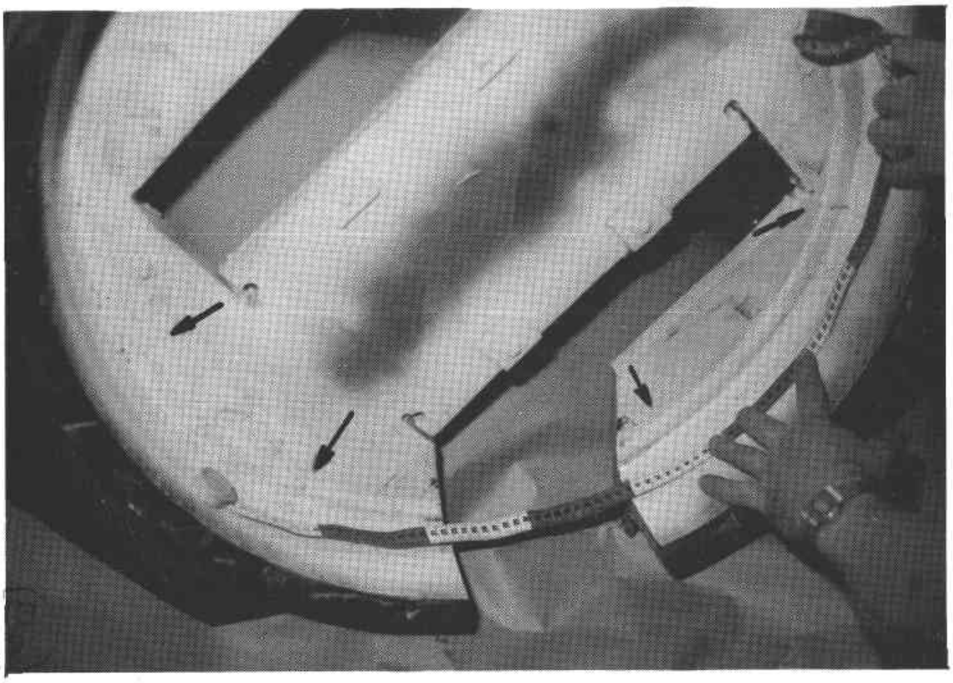


Fig. 9 Magnetic particle indications on the inside of the stud

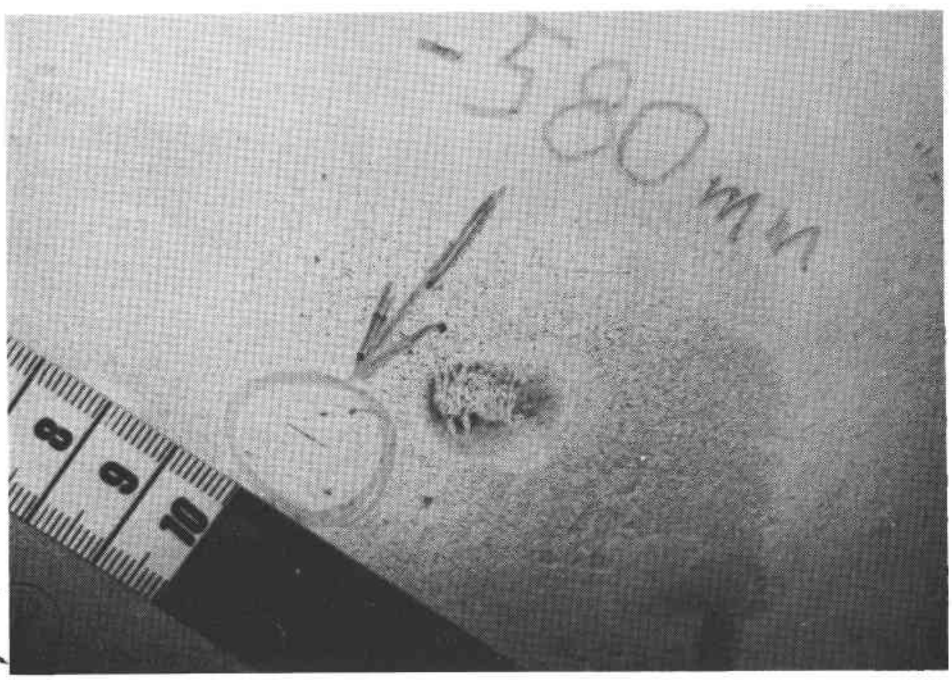


Fig. 10 Indications in the base material opposite the stud weld

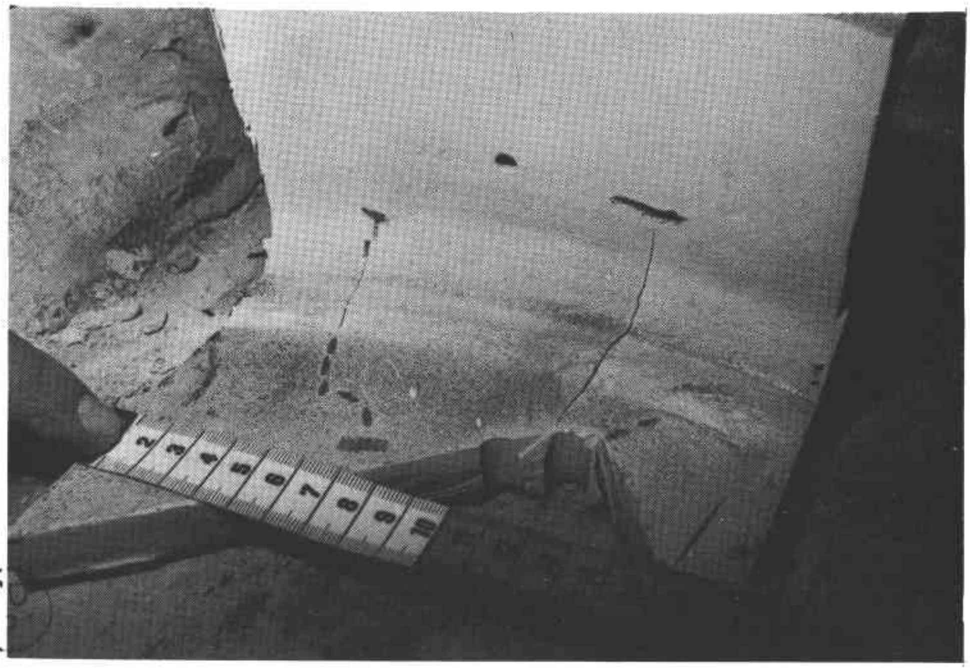


Fig. 11 US-indications in the prolongation of the surface cracks

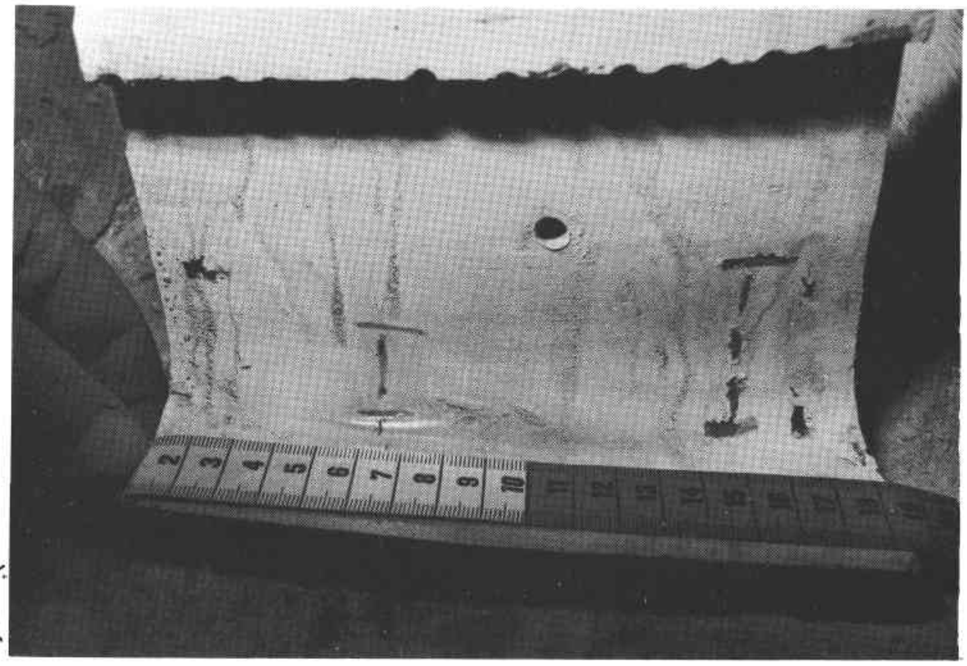


Fig. 12 Rear view of the sample from fig. 11

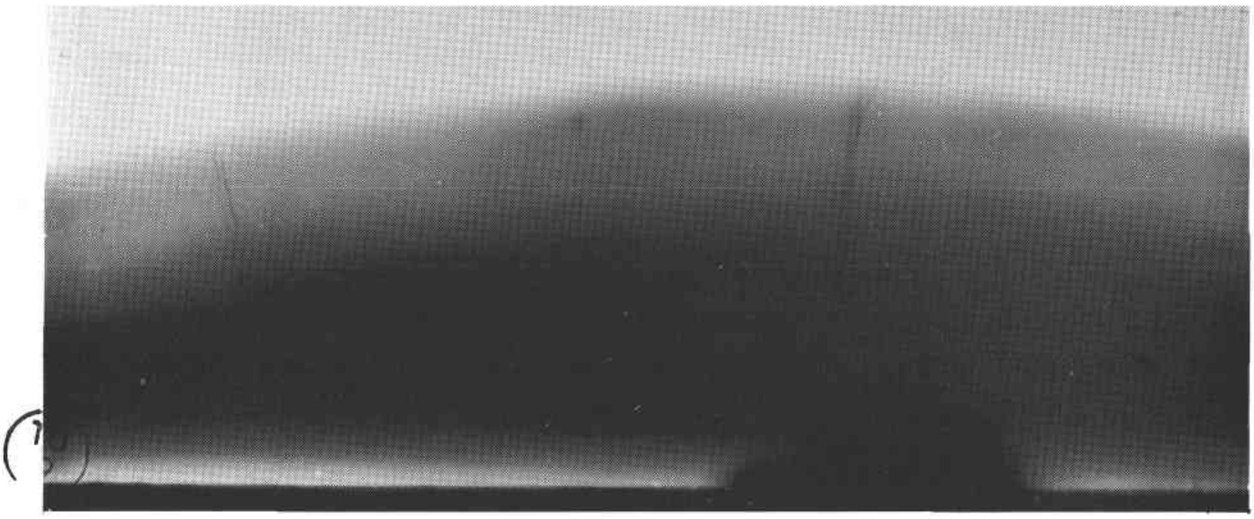


Fig. 12a X-ray indications in the vessel base 1:1

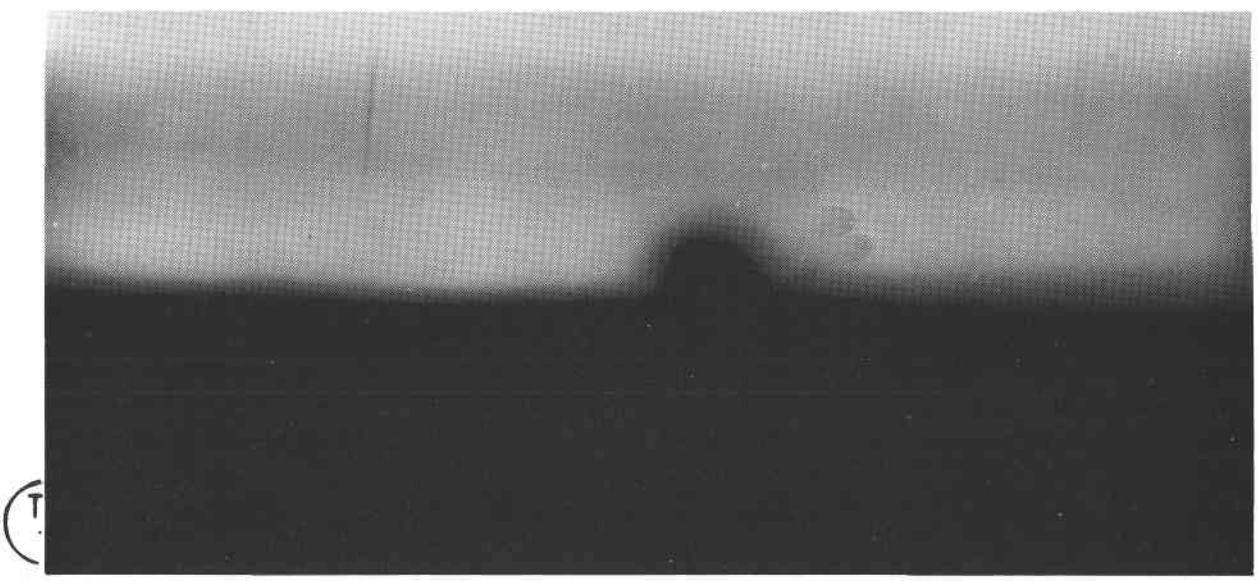


Fig. 12b X-ray indications in the stud 1:1

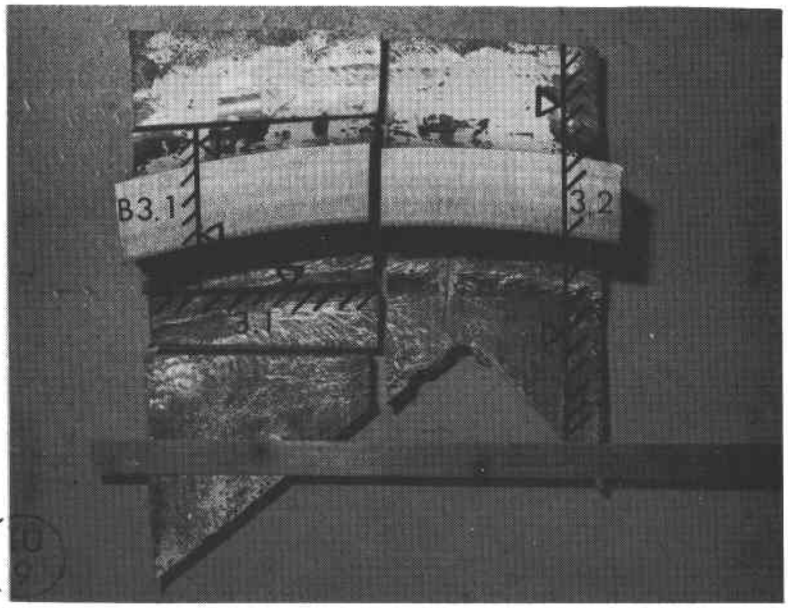


Fig. 13 Division of sample, sample 3

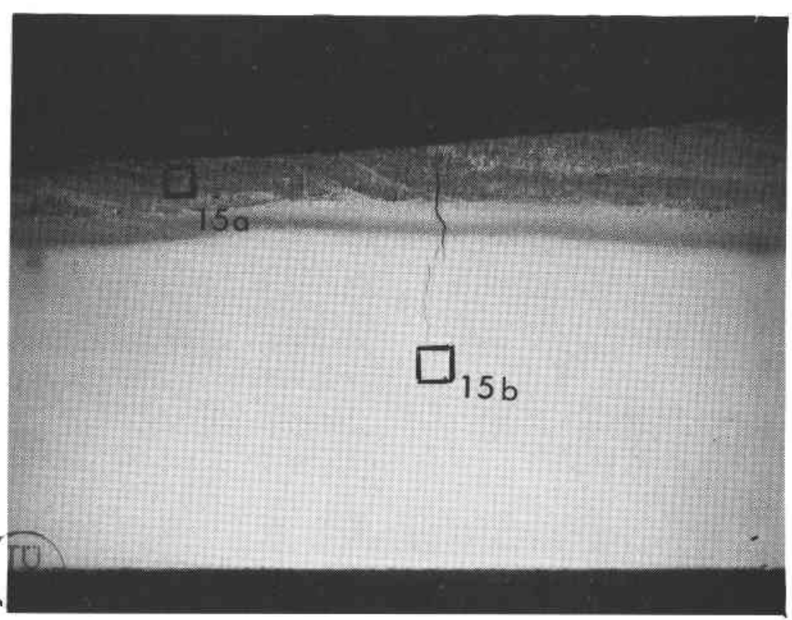
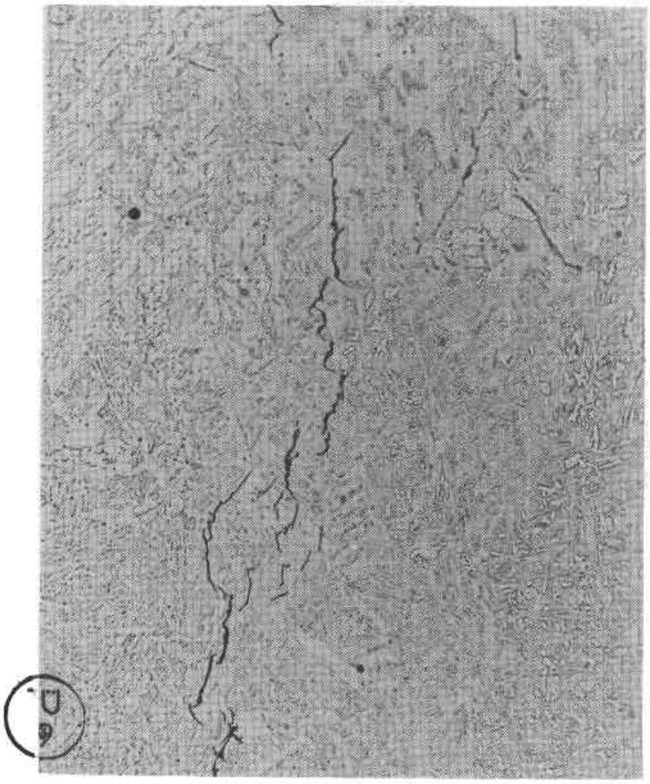


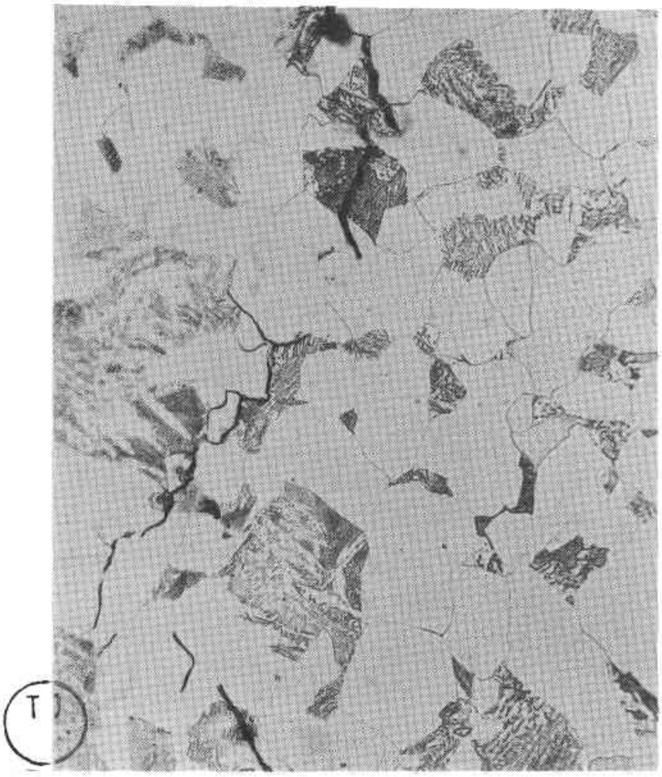
Fig. 14 Survey microsection 3.1 3:1



Detail from Fig. 14

crack in weld metal

Fig. 15a
500:1



Detail from Fig. 14

crack in base material

Fig. 15b
500:1

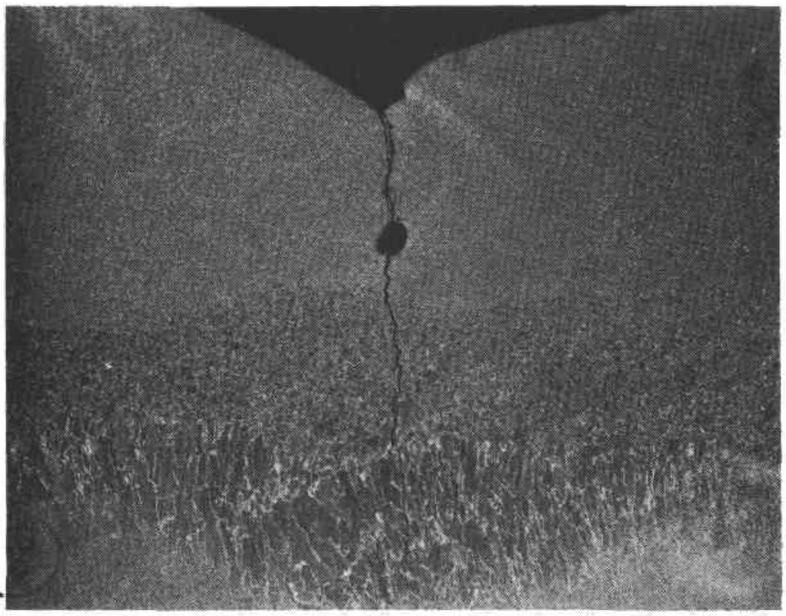


Fig. 15c Sample 4.2 10:1
longitudinal section through the manhole weld

Fig. 15d 200:1
Detail from Fig. 15c, start of crack

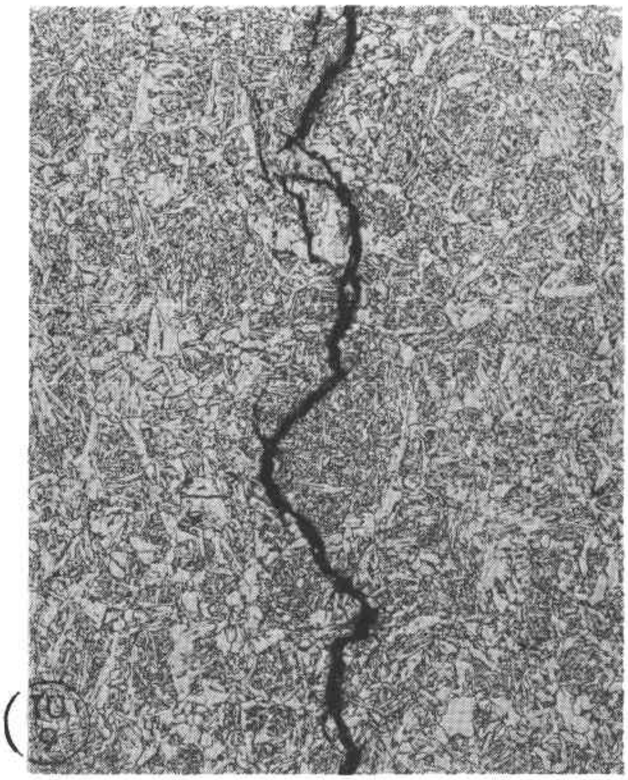


Fig. 15e 200:1

Detail from Fig. 15c, centre of crack

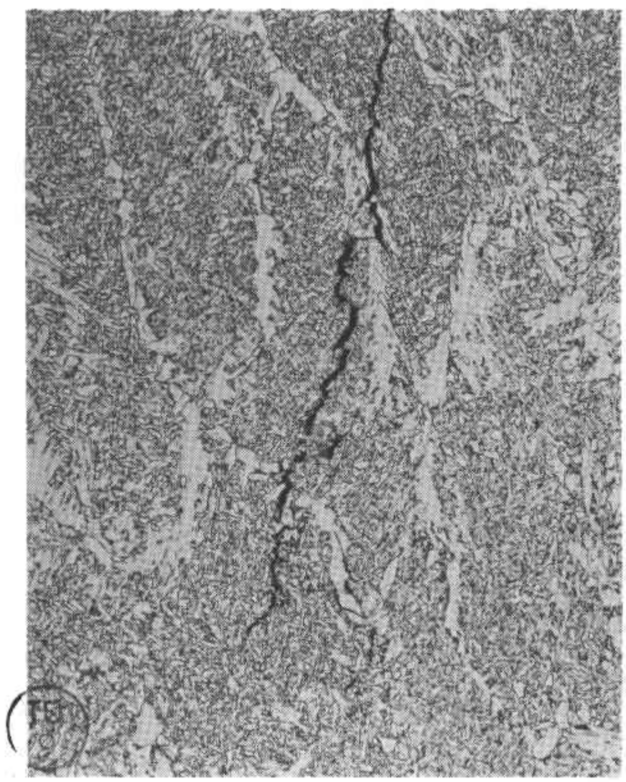


Fig. 15f 200:1

Detail from Fig. 15c, termination of crack

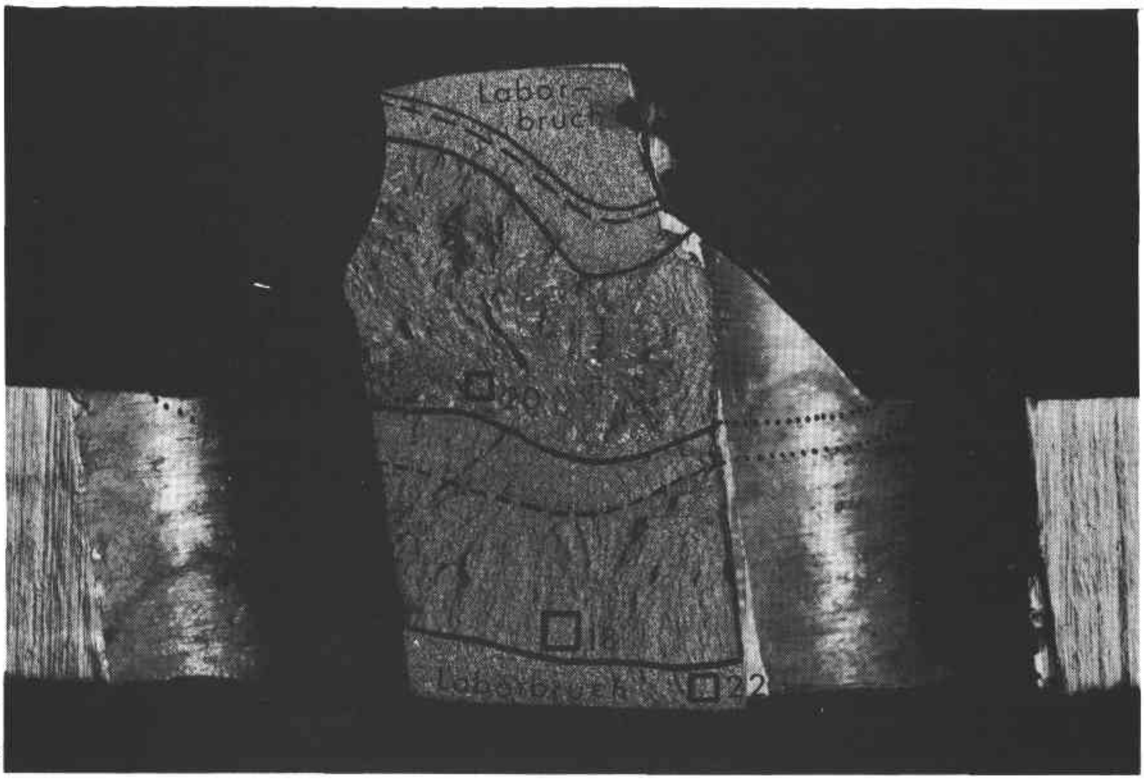


Fig. 16 Fracture surface "B 2.1" 2,3:1

Fig. 17 Weld buildup 2,3:1

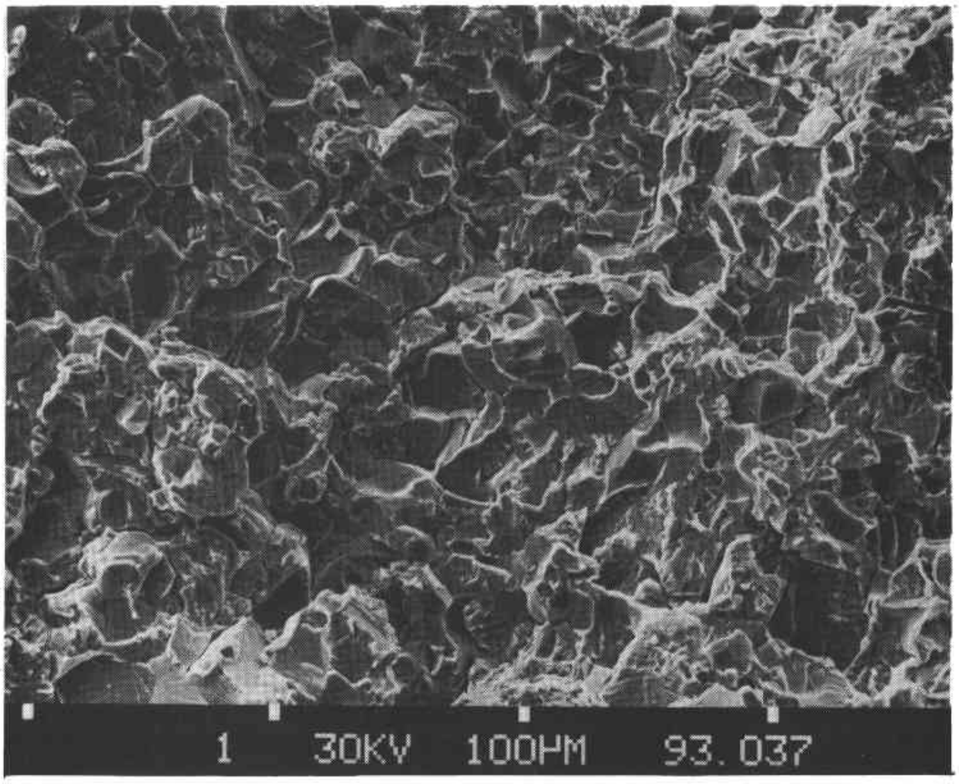


Fig. 18 300:1

Fracture surface in the damaged base material

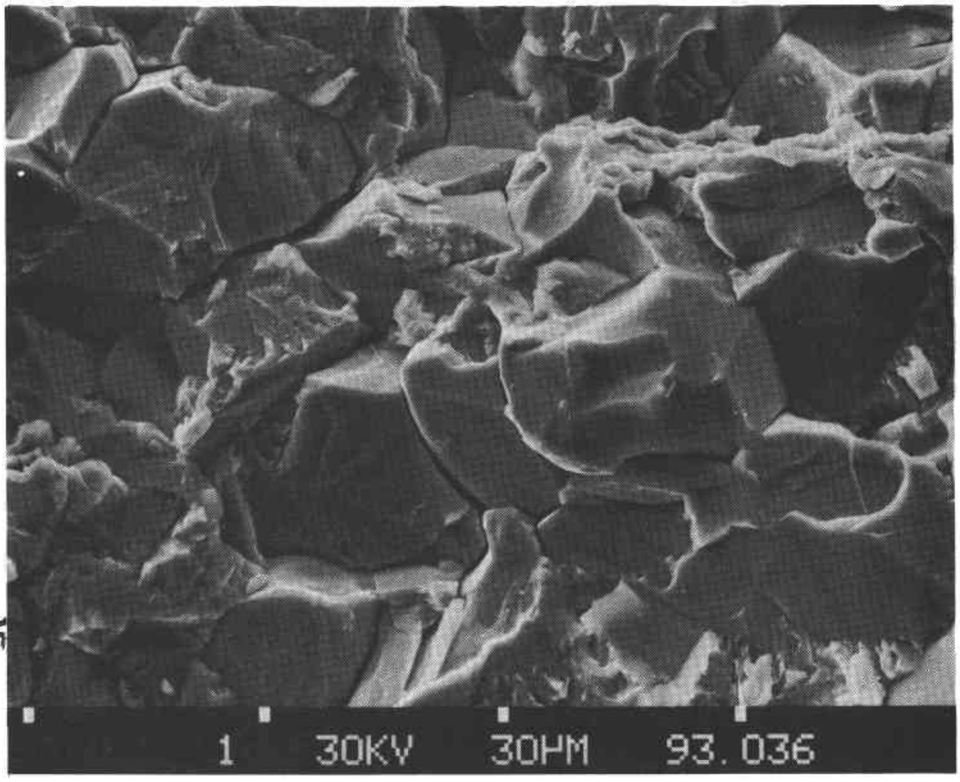


Fig. 19 Detail from Fig. 18 1000:1

Inter- and transcrystalline fracture with numerous intergranular cracks

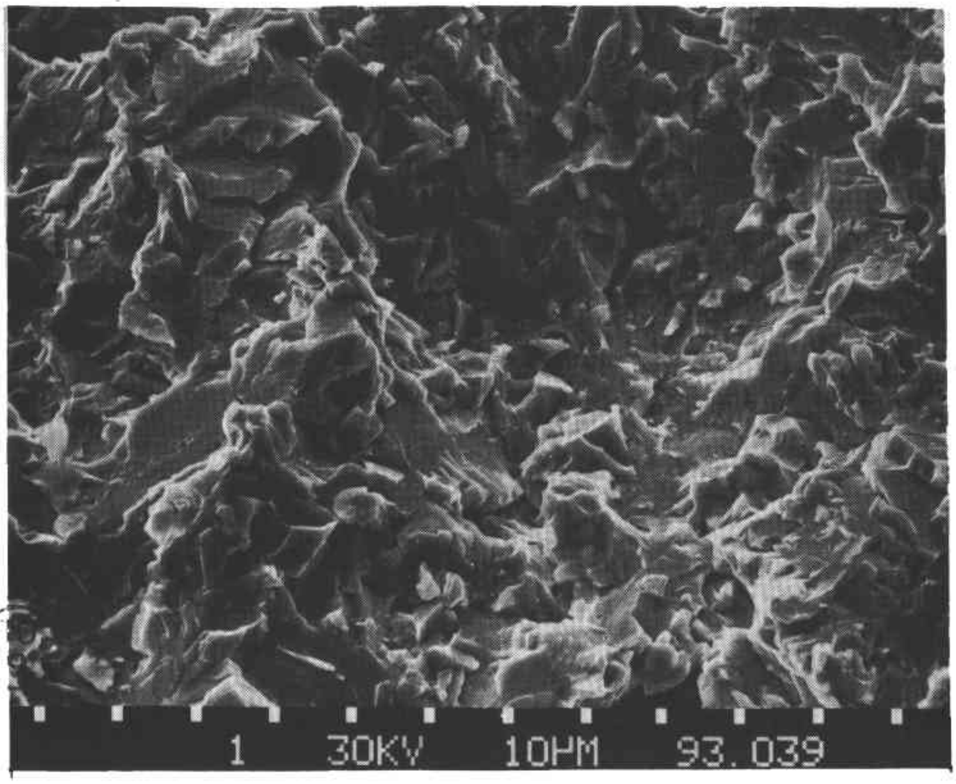


Fig. 20 1000:1

Fracture surface in damaged weld metal

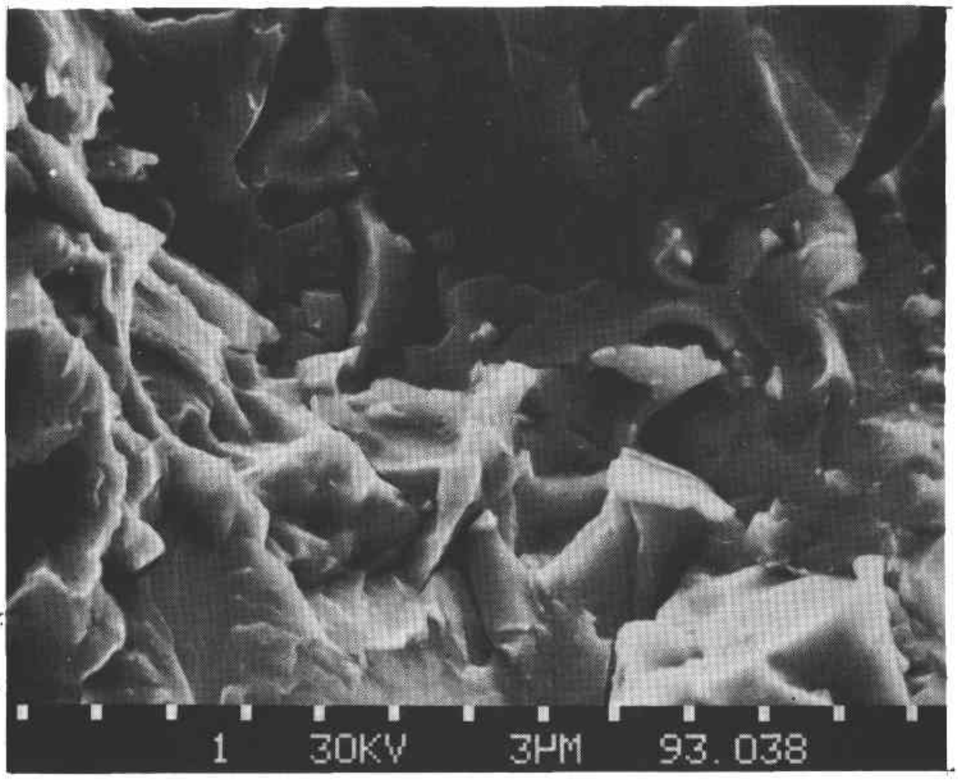


Fig. 21 Detail from Fig. 20 3000:1

Brittle fracture with intergranular cracks

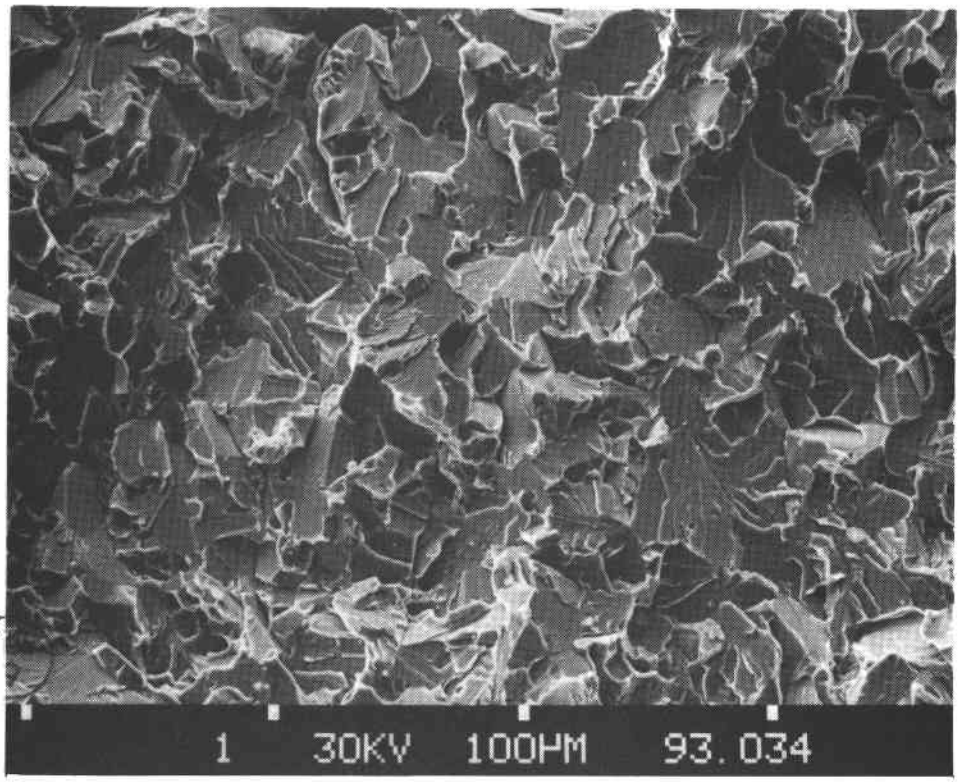


Fig. 22 Laboratory fracture surface 300:1
Cleavage fracture in base material

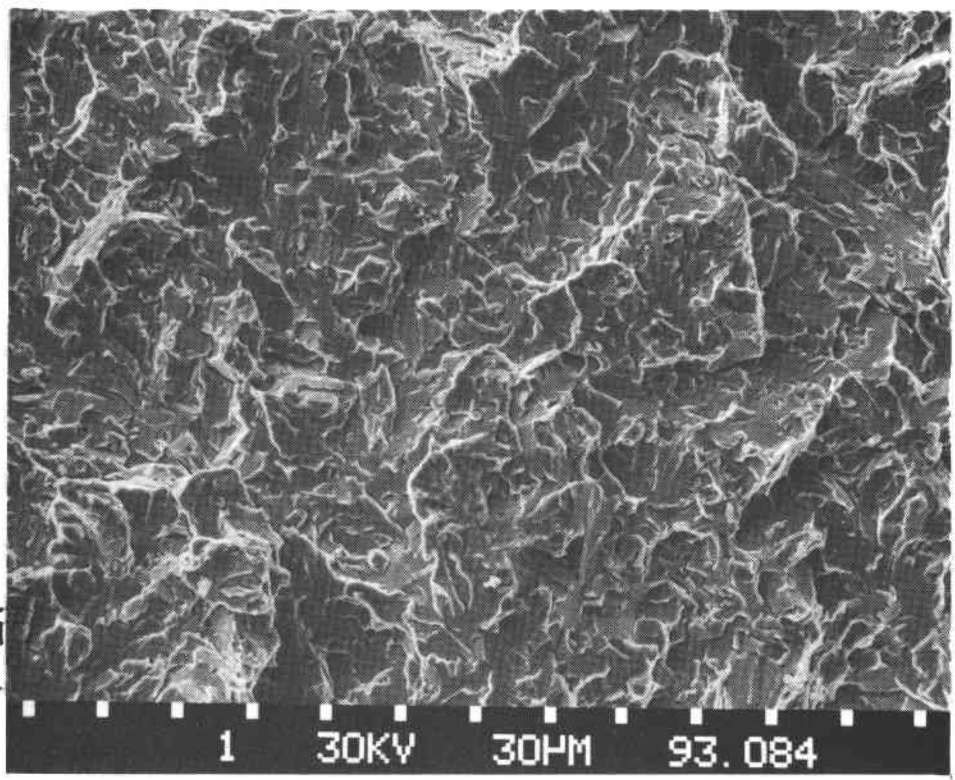


Fig. 23 Laboratory fracture surface 300:1
Cleavage fracture in weld metal

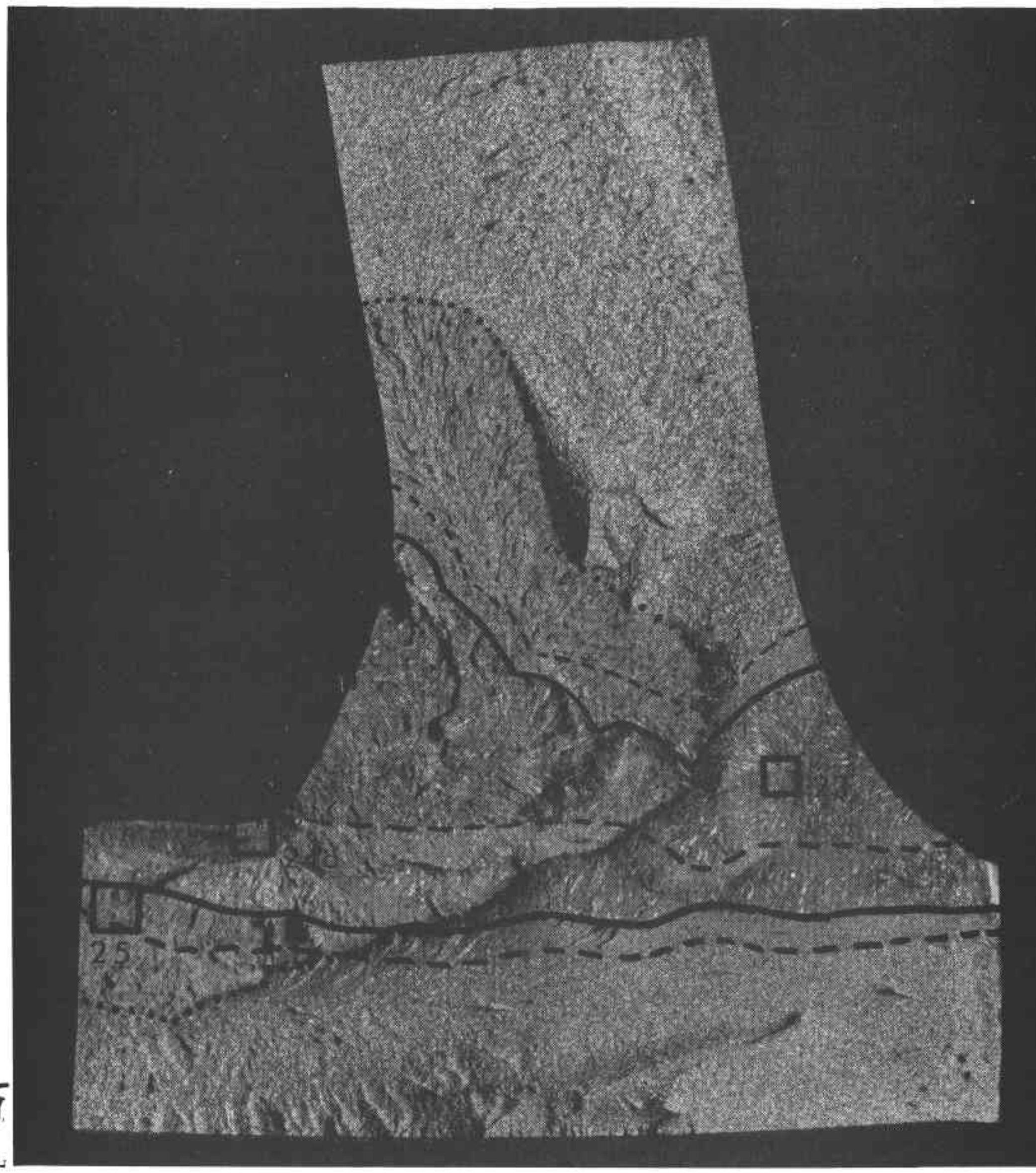


Fig. 24 Fracture surface stud weld 2,3:1

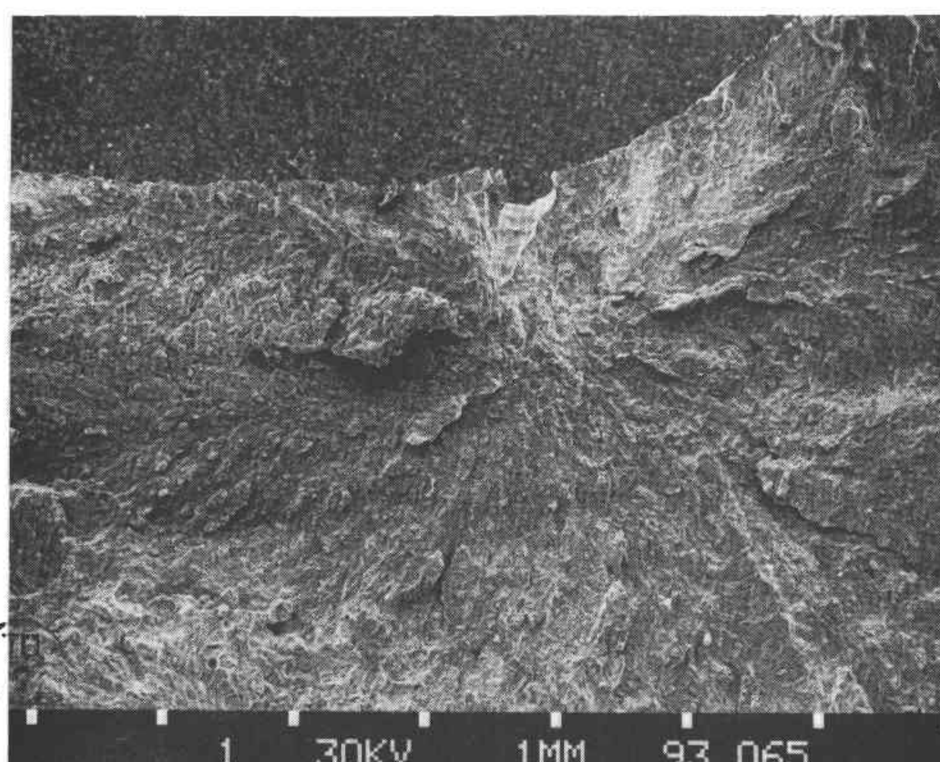


Fig. 24a Detail from Fig. 24 16:1

Welding flaw

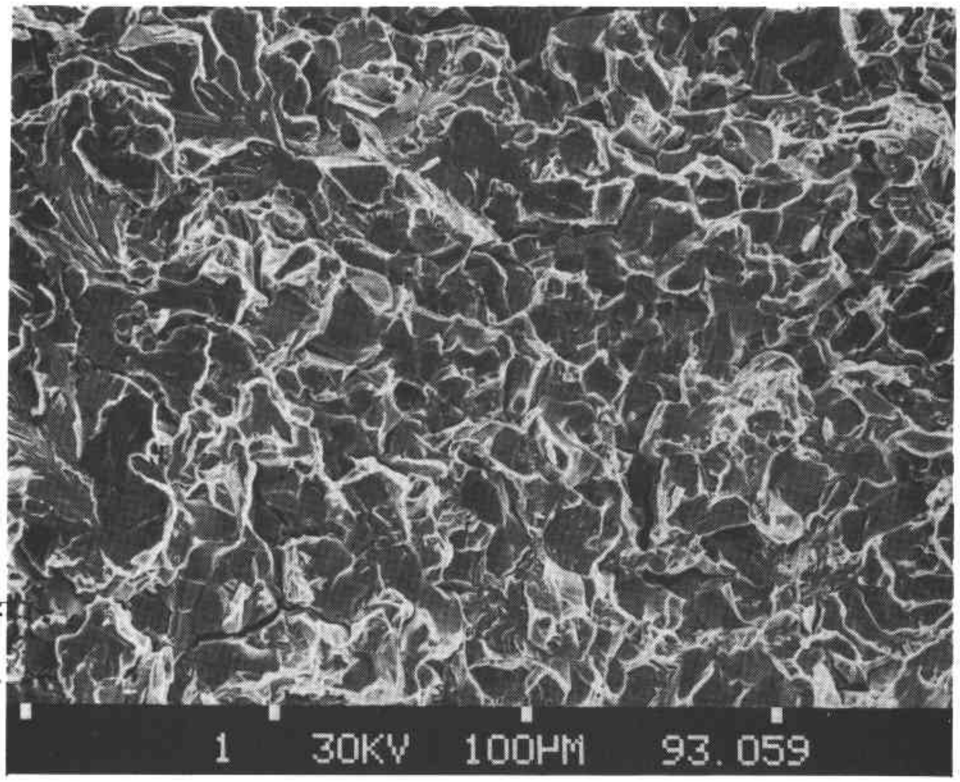


Fig. 25 Detail from Fig. 24 300:1

Interface between weld metal and base material

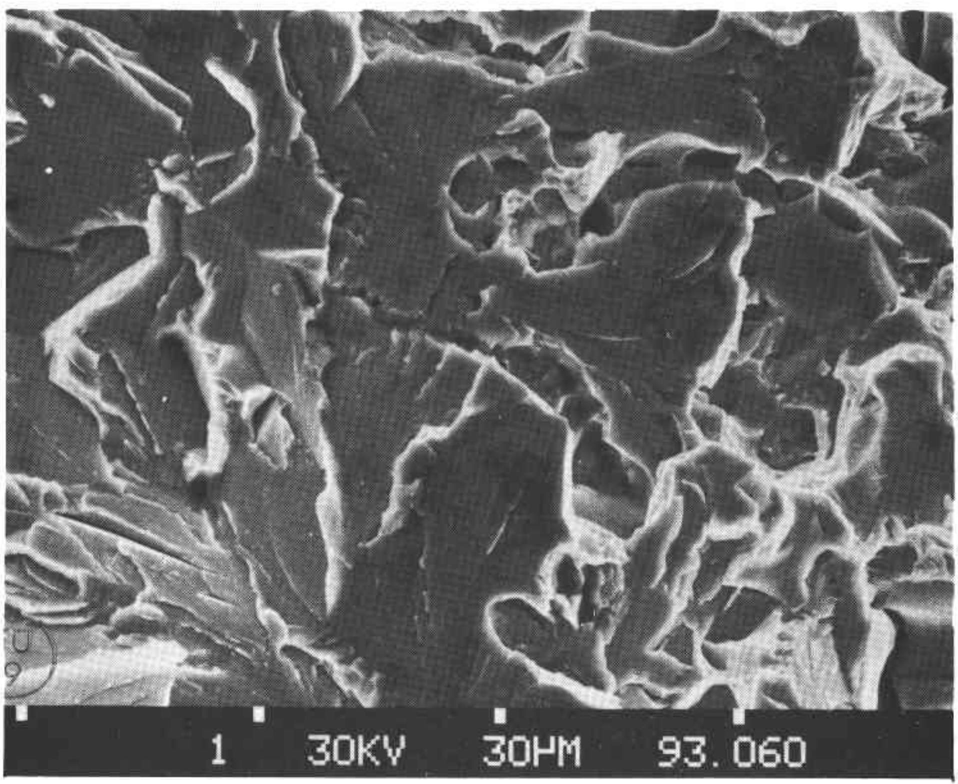


Fig. 26 Detail from Fig. 25 1000:1

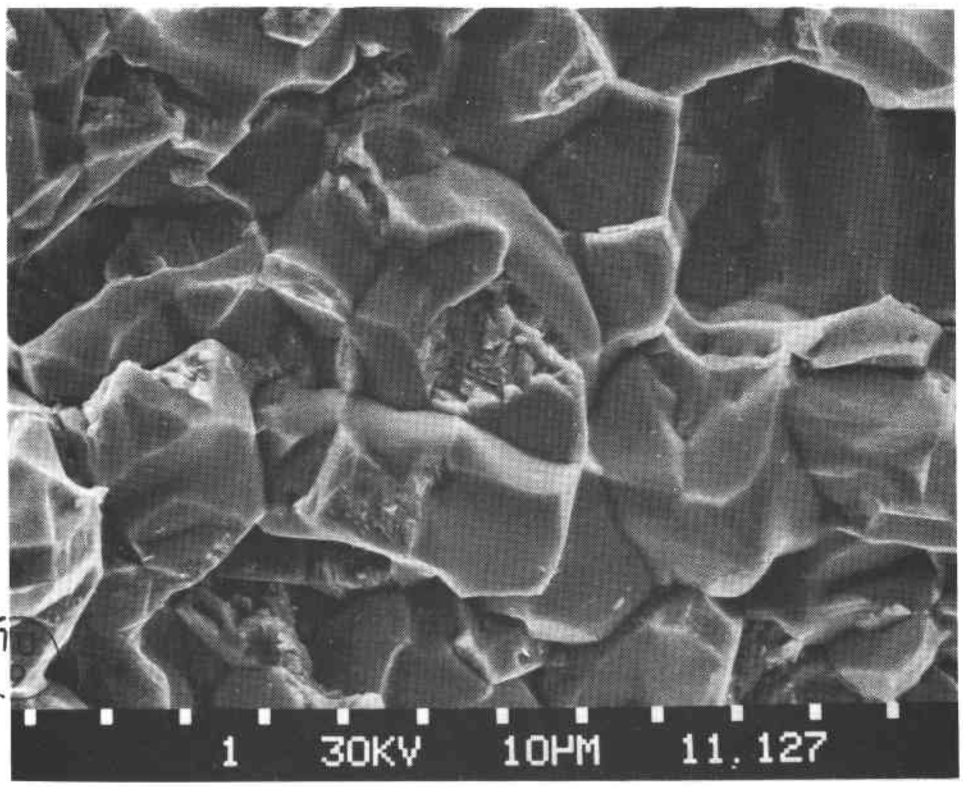


Fig. 27 Fracture surface base material 1000:1
Jones simulation sample in NaOH

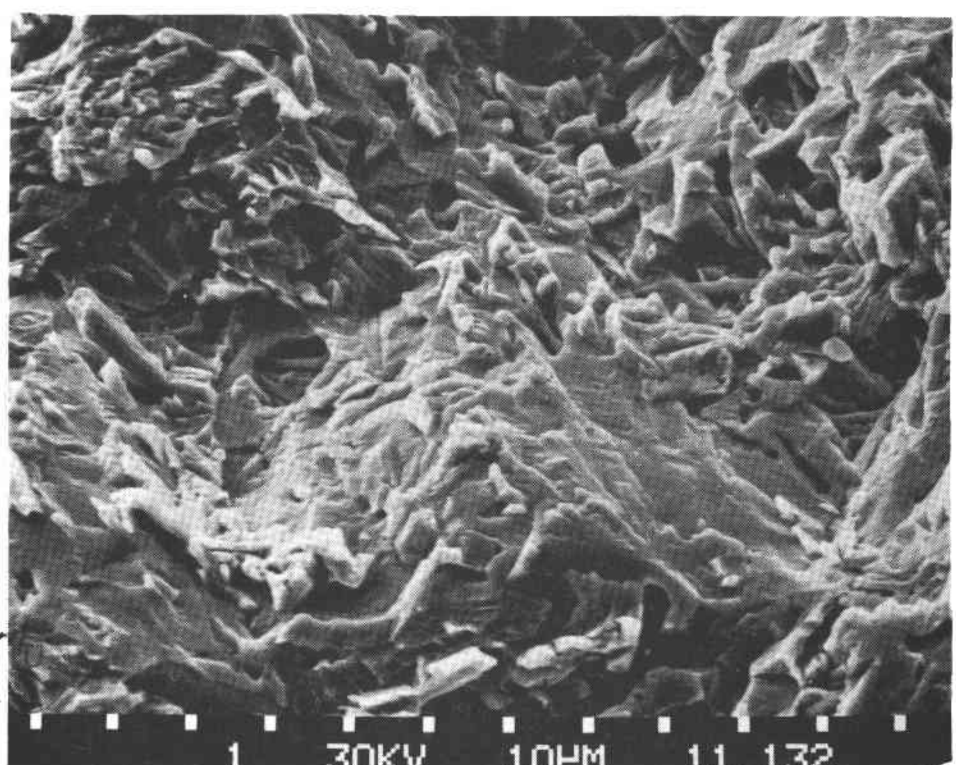
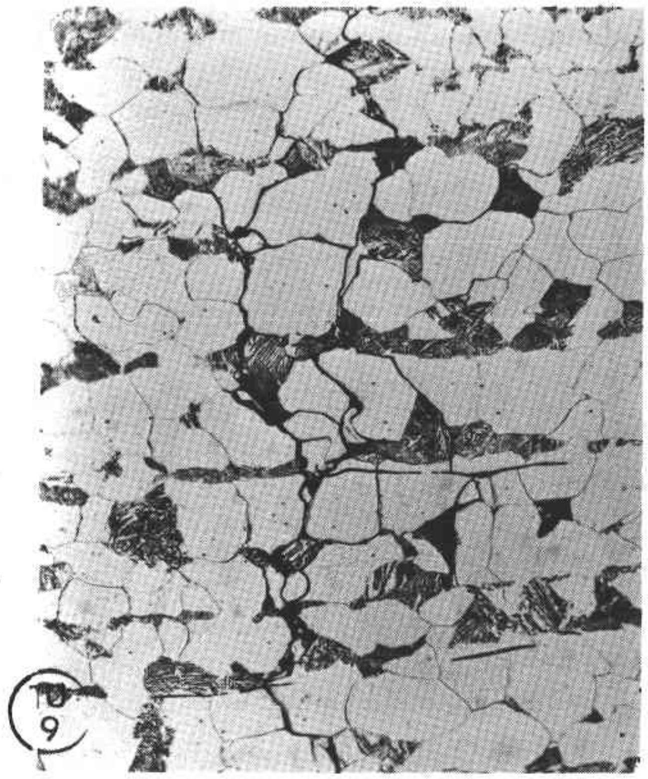


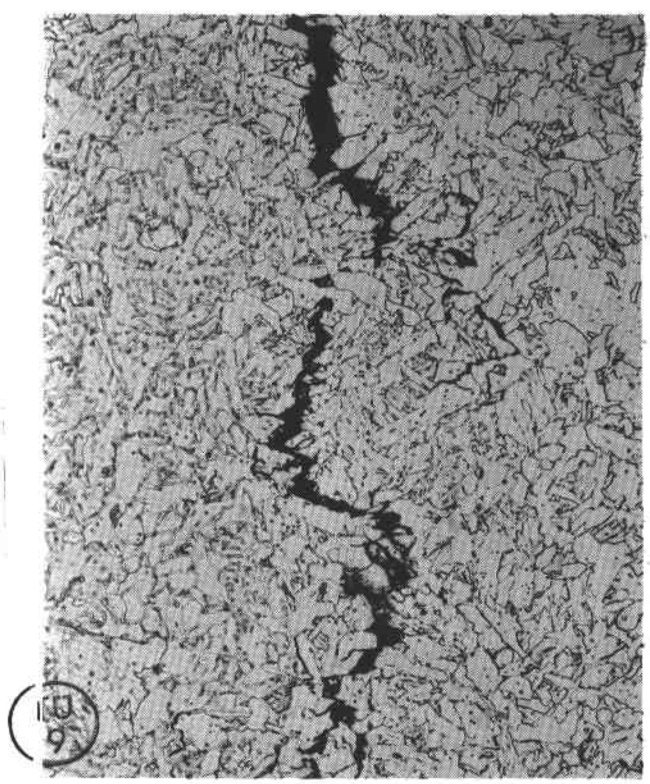
Fig. 28 Fracture surface weld metal 1000:1
Jones simulation sample in NaOH



Crack in base material

Jones simulation sample in NaOH

Fig. 29
500:1



Crack in weld metal

Jones simulation sample in NaOH

Fig. 30
500:1

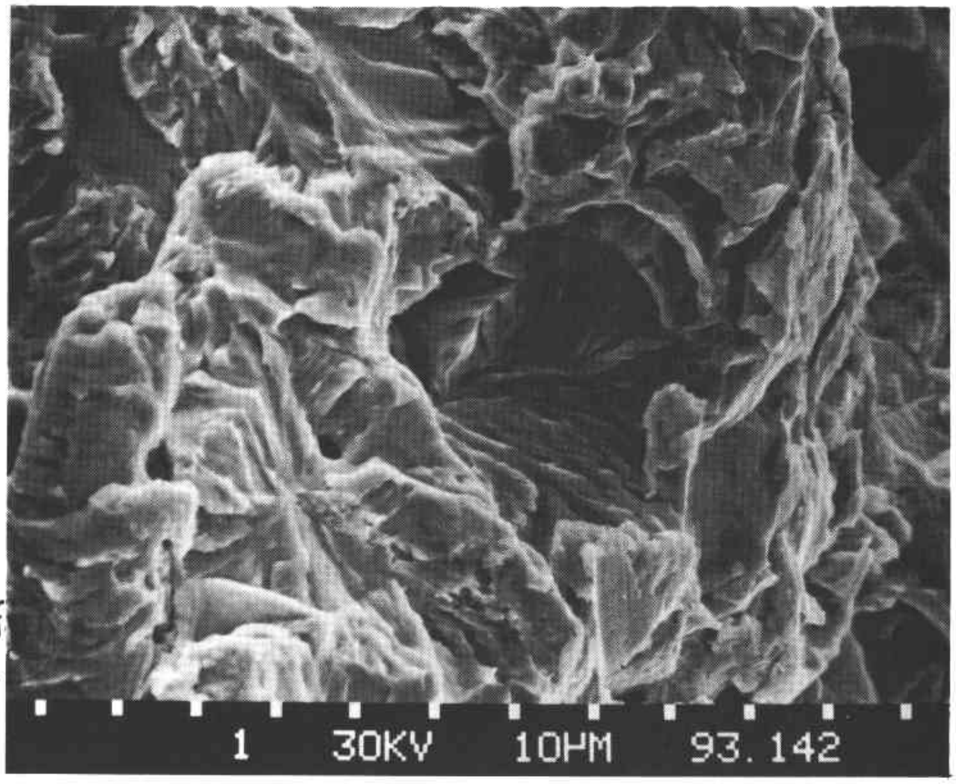


Fig. 31 Fracture surface base material 1000:1
Jones simulation sample in H_2S

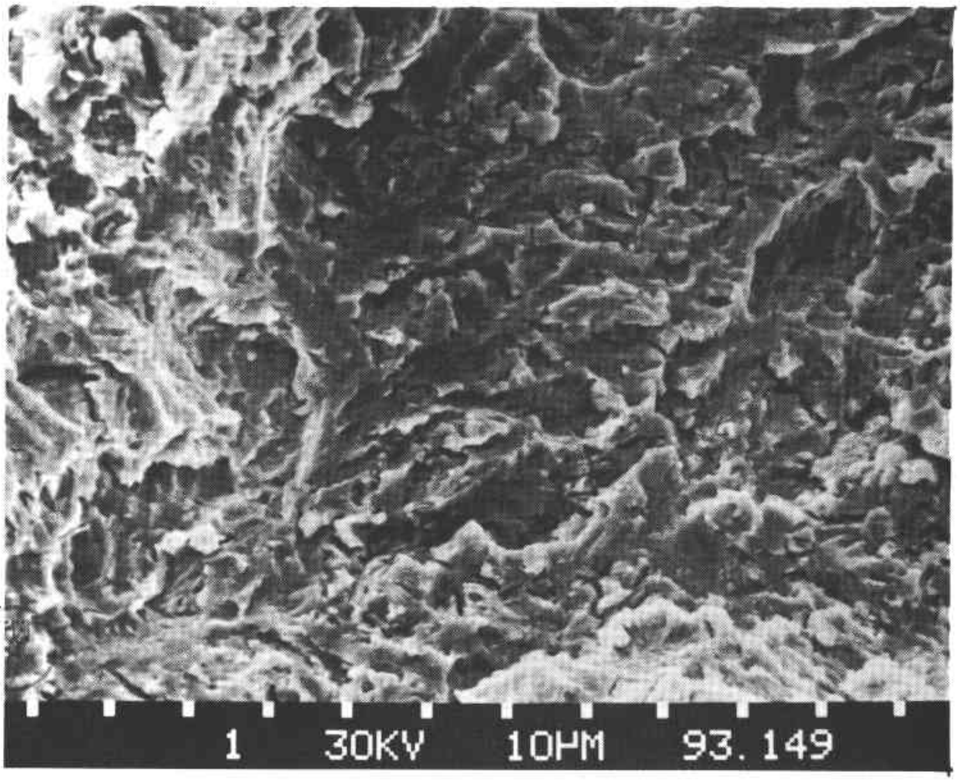


Fig. 32 Fracture surface weld metal 1000:1
Jones simulation sample in H_2S

Department for
Construction Supervision

TÜV RHEINLAND

Cologne, 16.06.1983
Test No.:211 022/2
922-wi-ms

REPORT
on
DAMAGE CAUSES
and
REMEDIAL MEASURES

Customer :	Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V. (DFVLR, Postfach 90 60 58, D-5000 Köln 90) Operating Agent for IEA-SSPS
Subject :	Regenerating Vessel in accordance with Drawing No.: 57.32.17634/8220
Manufacturer :	VOEST - ALPIN AG
Data on vessel nameplate :	Serial-No.: LL 01 BB 01
	Date : 1980
	Vessel-No.: 5781
	Dis.Press.: 8.5 bar
	Dis. Temp.: 450°C
	MEDIUM: Sodium
	Capacity : 4 500 L
Operator :	Sevillana, Spain
Site :	Almeria, Spain
Prepared by :	Dipl.-Ing. Wilters
No. of pages :	13
Annex :	1
Figures :	1 - 5

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0.0.0 Summary

A leakage in the form of a transverse crack extending into the adjacent base material has occurred at a welding seam of the Regenerating Vessel. Cracks were detected at pipe bracket seams. Only welding seams coming into contact with sodium were affected.

SN 9/2 , Manhole welding seam, Annex 1
SN X * , Pipe bracket seam, Annex 1

The other parts of the vessel did not exhibit any damages.

The following points were established:

- The hardness values and structural condition of base material and weld metal are normal.
- A sodium sample was of reactor quality.
- The fracture surface of the crack causing the leakage and a longitudinal crack in the root area exhibit features of damage due to stress corrosion cracking.
- The cracks at the pipe bracket seams were eliminated without a preceeding fractographic examination.

The laboratory examination, the test results and visual inspection of the vessel indicate that material stresses can be made responsible for the formation of the cracks listed above:

a) Unsuitable surface quality of the root of the connecting weld dished head to manhole stud (SN 9/2) on the medium side.

b) Inadequate constructive design at the joining welds of the pipe brackets thus hindering expansion.

Crack formation then occurs as the result of the interrelations described above.

* The welding seam is not included in the drawing of the vessel.

1.0.0 Temporal course of the damages

In the 37th. calendar week 1982, it became clear that oxides were forming on the insulation at the bottom of the Regenerating Vessel. Further examinations such as temperature measurement, inspection of the heating conductors strengthened the suspicion that sodium was leaking from the Regenerating Vessel.

During the subsequent operating period, the vessel was operated with solid sodium in the lower part.

2.0.0 Examinations and activities in Almeria

In the course of the 41st. week 1982, a start was made in the search for the damages at the stud Pos. 4 and bottom Pos.5 (Annex 1) on the outside of the vessel. The search was continued on the inside during the 3rd. calendar week 1983.

2.1.0 Outside inspection

The insulation of stud Pos. 4 and the bottom Pos. 5 was filled up with sodium and caked to the glass wool.
This caked mass was partly removed with hammer,chisel and compressed air tools. Small fires broke out repeatedly during these activities.

Fig. 1 presents the condition of the vessel after removal of the caked mass.

2.1.1 Surface crack test outside

The welding seam area SN 3/26 , the stud Pos. 4, the welding seams SN 9/2 and 1/8, the bottom Pos. 5 and the welding seam SN 3/25 (Annex 1) were each tested in two magnetization directions, both longitudinally and transversely. Alternating current yoke magnets were used. The pictures were produced using black magnetic particles.

2.2.0 Inside inspection

After the inside of the vessel had been cleaned using the vacuum distillation method and opened by means of a severance cut ~100mm above welding seam SN 9/2, the vessel was subjected to the following inspections:

2.2.1 Surface crack test inside

The total inner surface was tested in two magnetization directions, in each case both longitudinally and transversely. Alternating current yoke magnets were used. The picture was produced using fluorescent magnetic particle suspension. The Bertold test specimen was used to check the sensitivity.

2.2.2 Ultrasonic test inside

The ultrasonic test of the welding seams was performed with a sensitivity setting as specified in AD-Merkblatt HP 5/3. In accordance with the existing wall thickness, the substitute error value of 1.0 was taken as the basis for the registration limit. The test was effected with test angles 45^{o} and 70^{o} and with the normal search unit.

The longitudinal welds SN 1/7 and 1/8 were subjected to a 100% test, the circumferential welds SN 1/9 and 1/10 in the T-joint area to a 25 % test and the manhole welding seam SN 3/26 to a 100 % test.

2.3.0 Inner and outer visual inspection

The visual inspection of the outside was limited to the exposed area, the exposed manhole stud Pos. 4 and the lower dished head Pos.3. The inner surface was subjected to a 100 % visual inspection.

2.4.0 Sample taking

As shown in Fig. 3.1, a sample was taken from the welding seam area around the crack Fig. 2 and was immediately painted with paraffin on all sides to prevent contact with air, Fig. 3.2.

3.0.0 Results of the examinations

A crack, which is illustrated in Fig. 2, was found to be the cause of the leakage. The length of the crack is approximately 35 mm on the outer and inner sides. It begins approximately 4 mm above the lower cover pass side of welding seam SN 9/2 , passes upwards through the seam and ends in the base material of the stud, Pos. 4, Annex 1.

The total root pass SN 9/2 is illustrated in Fig. 4.1 (without the sample Fig. 3.2). It exhibits poor formation over large sections, e.g. drops, severe root ripples and notches in longitudinal and transverse direction, Fig. 4.2. Three adjacent root beads indicate a multiple repair in the root area in Fig. 4.2.

Cracks were evident at the ends of the fillet welding seams SN X (Annex 1). The pipe brackets were severed from the vessel wall (Fig. 5) , the remaining pieces were ground down to the wall surface until no further crack indications were detected (specified wall 12 mm, after grinding 10.8 mm).

3.1.0 Surface crack test (Points 2.1.1 and 2.2.1)

No crack indications were detected outside the areas listed above.

3.2.0 Ultrasonic test (Point 2.2.2)

The test of the butt welds and the welding-in seam of the manhole stud did not result in any indications subject to registration.

3.3.0 Inner and outer visual inspection (Point 2.3.0)

The inner and outer surfaces were covered with a slight rust film, which, however, did not impair the assessment. Please refer to Fig. 5 in this respect.

With the exception of the root pass SN 9/2 and the fillet welding seam SN X, all welding seams were ground. The inner and outer visual inspection did not give rise to any objections.

4.0.0 Summary of the examination results

The results of the diverse examinations performed are briefly summarized below :

4.1.0 Damage situation of the vessel on site

4.1.1 The weld joint (SN 9/2) of the manhole stud Pos. 4 to the dished head Pos. 5 exhibits a crack, as shown in Fig. 2.

4.1.2 The welding seams SN X (not identified in the drawing) exhibit fine cracks at the ends.

4.2.0 Report on the damage examination of the Regenerating Vessel dated 25.05.1983

The sample illustrated in Fig. 3.2 was examined in the Institute for Materials Testing with the following results :

- 2 types of cracks were detected : A main crack at right angles to the welding seam, originating from a starting point with root sagging, and a longitudinal crack, originating from a root notch with subsequent lack of fusion.

- The main crack covers the total welding seam and reaches into the base material on both sides of the seam.

- On the root side, more than half the wall thickness of its fracture surface was covered with sodium.

- The crack length on the inner and outer surfaces is identical.

- The course of the crack in the base material is inter- and transcrystalline, and primarily transcrystalline in the weld metal.

- The longitudinal crack exhibits the same inter- and trans-crystalline course as the transverse crack, whereby the transcrystalline fraction similarly predominates in the weld metal.

- The structural condition of base material and weld metal is normal.

- The partial weld metal control analysis does not indicate any material confusion.

The metallographic and fractographic picture of the cracks therefore exhibits the same features as that of the Cold Storage Vessel, and therefore similarly points to stress corrosion cracking as the cause of the damage. The detrimental influence of welding flaws in the root area is, however, much more obvious in the case under consideration than in that of the Cold Storage Vessel.

It was not possible to detect the composition of the medium causing the detected stress corrosion cracking during this examination either.

5.0.0 Summary and evaluation of the examination results with reference to the cause of the damage

The transverse and longitudinal cracks which have appeared at the weld joint (SN 9/2) exhibit clear features of intercrystalline stress corrosion cracking.

The fine cracks of welding seams SN X could not be examined in the laboratory as samples could not be taken.

The cracks originate exclusively on the inside of the vessel coming into contact with sodium near faults resulting from the design and the manufacture.

The material 15 Mo 3 is present and must be accepted in its quality as steel which is not completely resistant to cracking in caustic solutions. It is up to research to offer an explanation for the medium side. Subsequently, in order to evaluate the cause of the damage, it only remains to discuss the stress necessary for crack formation. This comprises residual stresses due to welding, load stresses due to internal pressure and temperature differences as well as peak stresses from notches caused by the design and the manufacture. The various areas of damage are discussed in the following from these points of view.

5.0.1 Manhole welding seam (SN 9/2)

The surface condition does not comply with the requirements of the General Specification RVS CRS-02 dated 15.03.1978, which contains the following requirement on page 5 under point 4 "Surface conditions of the welds" :

> "At the pressure-loaded components, all longitudinal, circumferential and weld-in seams shall be grinded - if possible - from inside to be free of notches."

Thereby the limitation "if possible" is understood as applying to welds which are not accessible from the inside due to the dimensions of the component (e.g. a pipe of < 500 inner Ø) and which can therefore only be welded from the outside. On the basis of the knowledge which can be drawn from the damage in question and which confirms this regulation, all possibilities should have been exhausted during design and construction to guarantee notch-free surfaces on the inside of the components.

The General Specification stipulates TIG welding for the root, obviously to ensure that the roots coming into contact with the medium are as smooth as possible. The weld formation discovered on the inside neither complies with this regulation nor with the requirements of the AD-Merkblatt HP 5/1 nor with the requirements of quality class BS according to DIN 8563, Part 3, where only flat local root concavities and notches are admissible over seams welded on one side, but where lack of fusion and poor alignment of plate edges amounting to 4 mm are inadmissible.

Fig. 4.2 gives an impression of the manufacturing quality. A horizontal multiple repair has been performed in the area X. The dripping liquid metal drops (see Point 4.2,Report prepared by Institute for Materials Testing, page 4, second dash) adhered to the surface in the damage area (sample).

5.0.2 Pipe bracket seams SN X (Annex 1)

The pipe below S1 is firmly welded to the wall of the vessel via the pipe bracket by welding seams SNY and SNX.

As a consequence of the rigid connection, the welding seams SNX must withstand all operational loads, namely different thermal expansions (vessel/pipe) and pressure fluctuations leading to alternating bending load. The surface quality of these welding seams does not comply with the General Specification named in Point 5.0.1.

5.1.0 Comprehensive evaluation

The results of the examinations can be comprehensively evaluated as follows :

- On the basis of the determined hardness values, the structural inspections and a weld metal analysis, it can be stated that the damages are not due to the base material and the weld metal deviating from the specified requirements.
- Outside the damage areas, the vessel is in perfect condition as regards the welding seams and the total inner surface. A complete magnetic particle inspection performed with the highest possible sensitivity did not exhibit any further crack indications. The ultrasonic test of the butt welds did not result in any indications subject to registration.
- A sodium sample taken from the specimen was of reactor quality.

- The fracture surfaces of the cracks and the course of the cracks in the material structure exhibit the features of damage due to stress corrosion cracking. Materials, which could have caused such corrosion cracking, were not detected on the fracture surfaces.

- The root formation of the welding seam manhole stud / dished head does not even approximately comply with the specifications. Sharp notches, lack of fusion and severe drops produced an inner surface covered with notches.

- The constructive design of the joining welds of the pipe bracket (pipe S1 with welding seams SNY and SNX) and the vessel wall hinders expansion and hence causes the build-up of higher alternating bending stresses. In the area around the ends of the seams SNX, these stresses are further increased by the stress concentration factor due to the notch-covered surface.

The laboratory examinations, the test results and the visual inspection indicate that material stresses can be made responsible for the formation of the cracks described above :

a) Unsuitable medium-side surface quality of the root of the connecting weld dished head / manhole stud (SN 9/2).

b) Inadequate constructive design at the joining welds of the pipe brackets thus hindering expansion.

Crack formation then occurs as the result of the interrelations described above.

6.0.0 Repair of the vessel

6.1.0 Prerequisites for repair

On the basis of the results of the examinations described above, the following principles were established for the repair :

- Avoidance of welded-on parts on the inside of the vessel.
- Maximum accuracy in the preparation of the welding edges to minimize warping due to welding and the residual welding stresses.
- Stress relief heat treatment of the welding seam SN 9/2.

The above requirements were entered in the repair programme of the company Voest Nos. S04 and S05.

6.2.0 Execution of the repair

The repair work was executed in the period 10.01.1983 to 23.02.1983. The bottom, Pos. 5, was renewed and most accurately fitted.

6.3.0 Evaluation of the repair

Employees of the TÜV Rheinland performed the following activities during supervision of the repair work :

- Complete supervision of the fitting and welding work.
- Visual inspection of the root pass.
- Evaluation of the X-ray films, performance of the surface crack test and ultrasonic tests.
- Control of the heat treatment.

It is confirmed that the repair work performed fulfils all the prerequisites for equating the vessel with a new vessel.

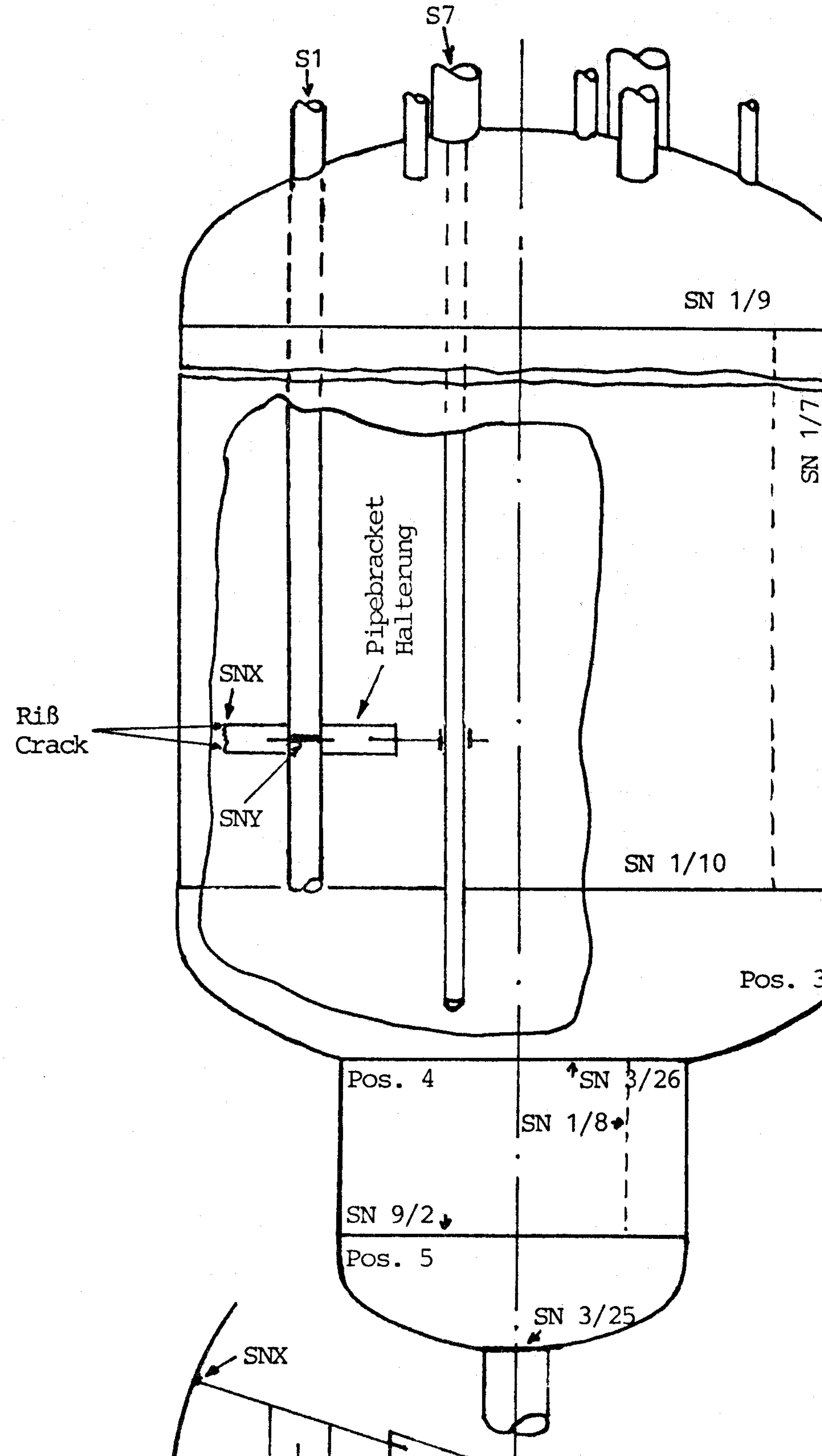
Technischer Überwachungsverein Rheinland e. V.
Zentralabteilung
Bauüberwachung von Großanlagen
Der Sachverständige

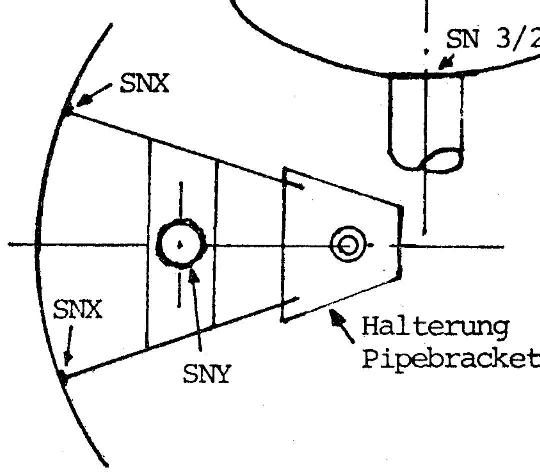
Wilt

Dipl.-Ing. Wilters

Anlage 1

Annex 1





The welding seam SNX and SNY is not included in the drawing of the vessel.

Die Schweißnähte SNX und SNY sind in der Zeichnung des Behälters nicht aufgeführt.

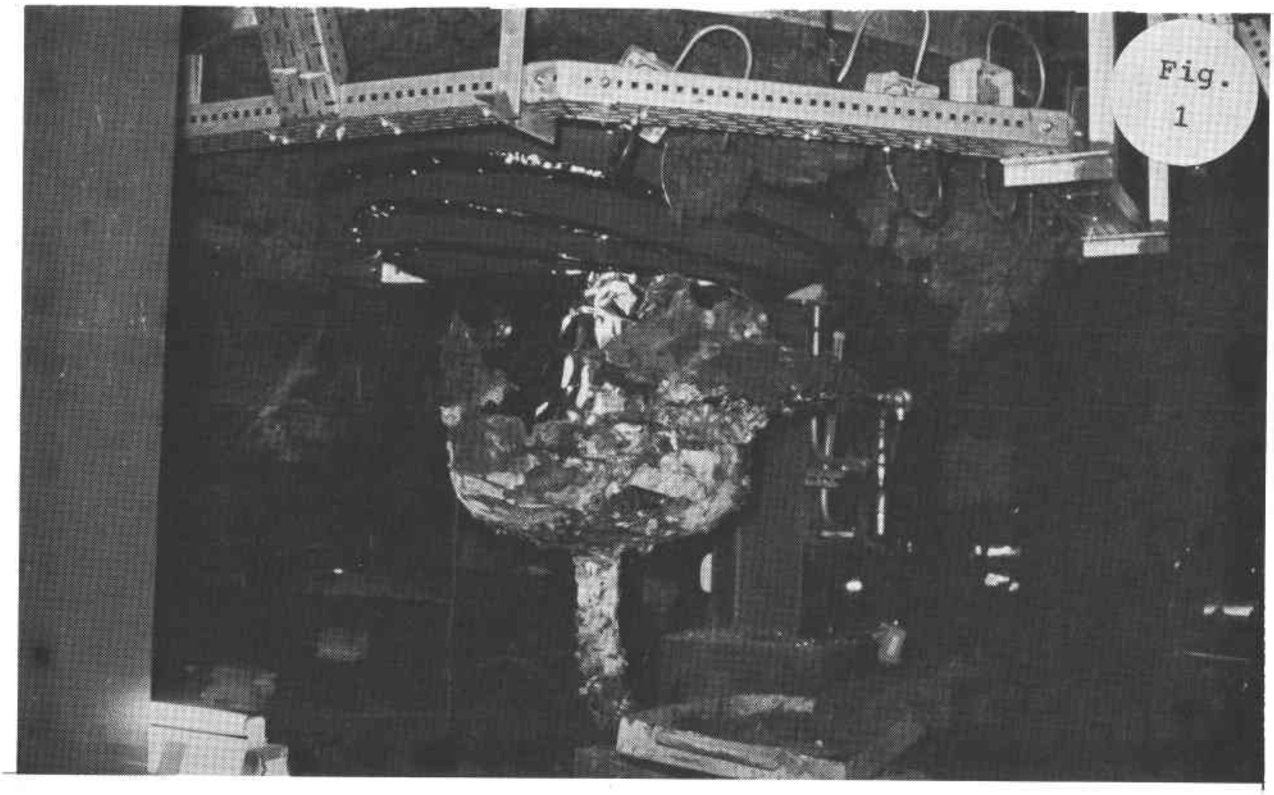


Fig. 1

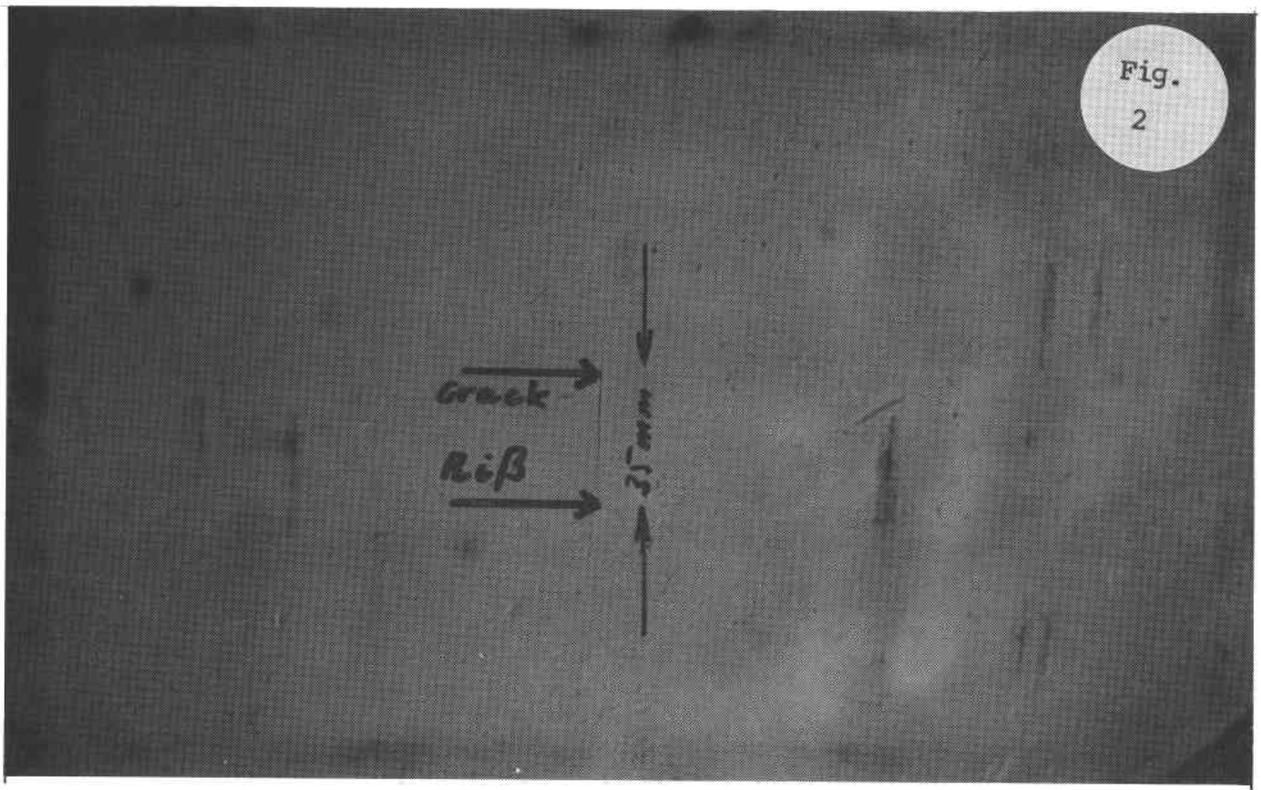


Fig. 2

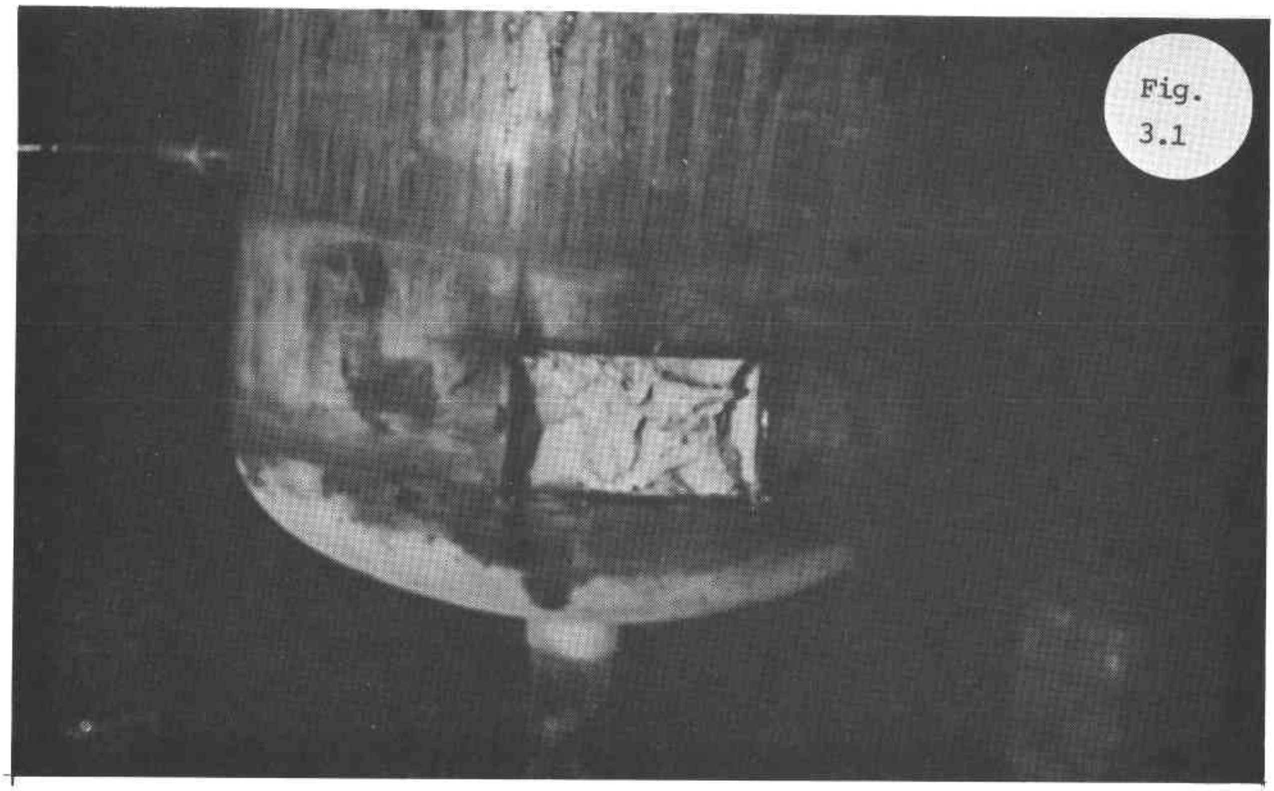


Fig.
3.1

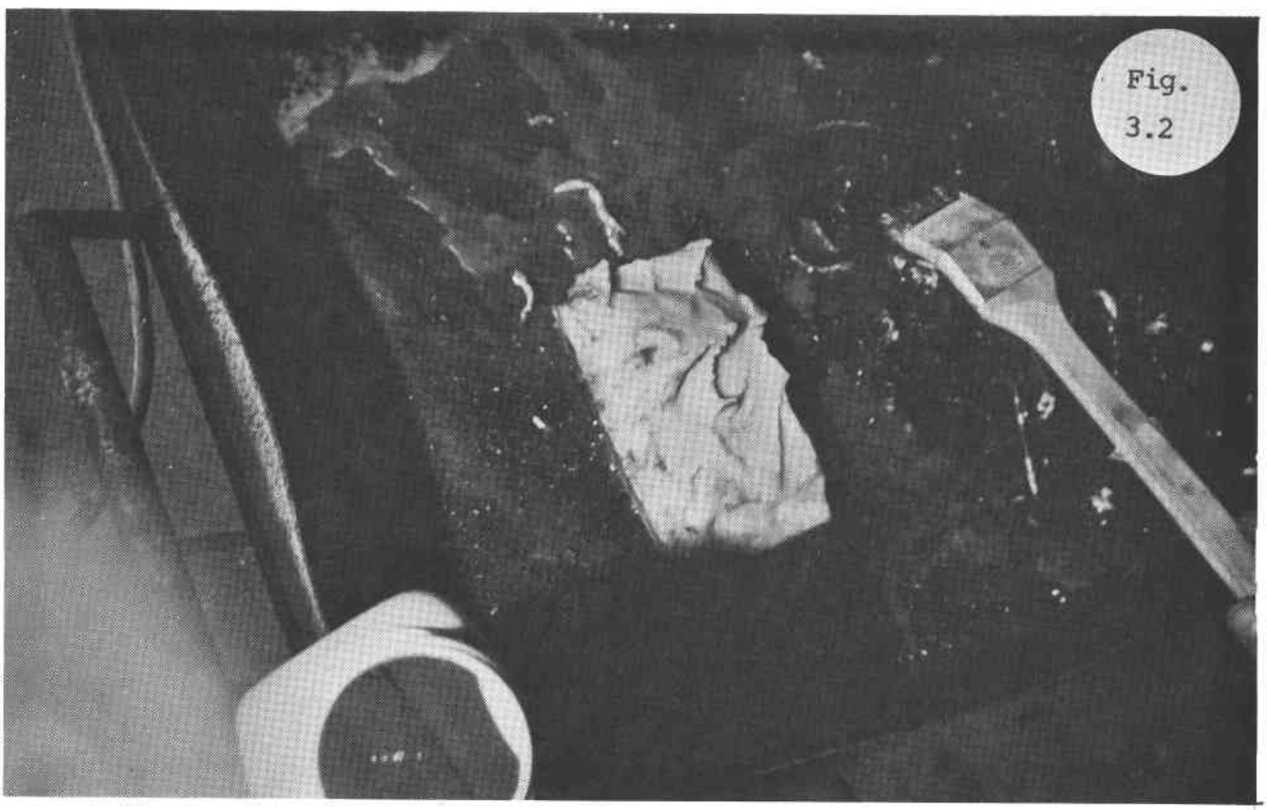


Fig.
3.2

Fig. 4.1

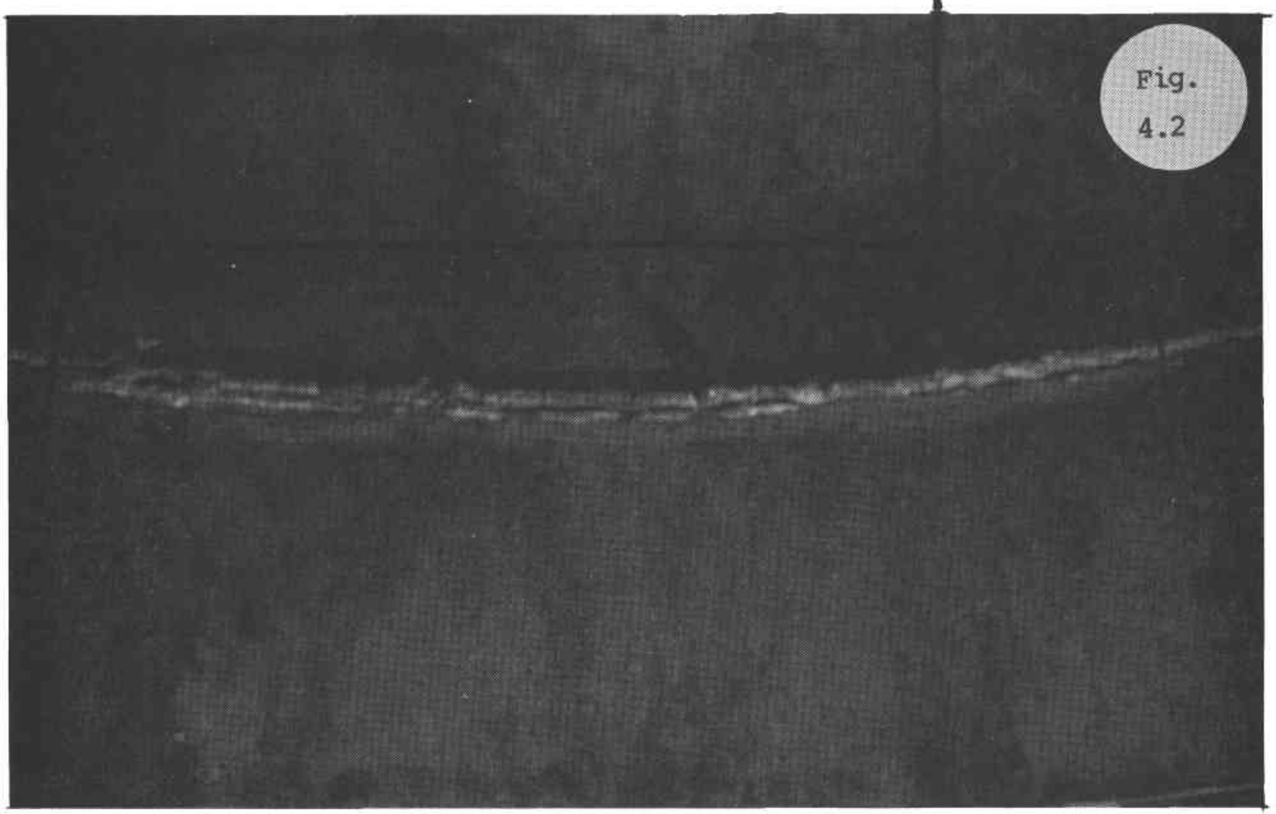


Fig. 4.2

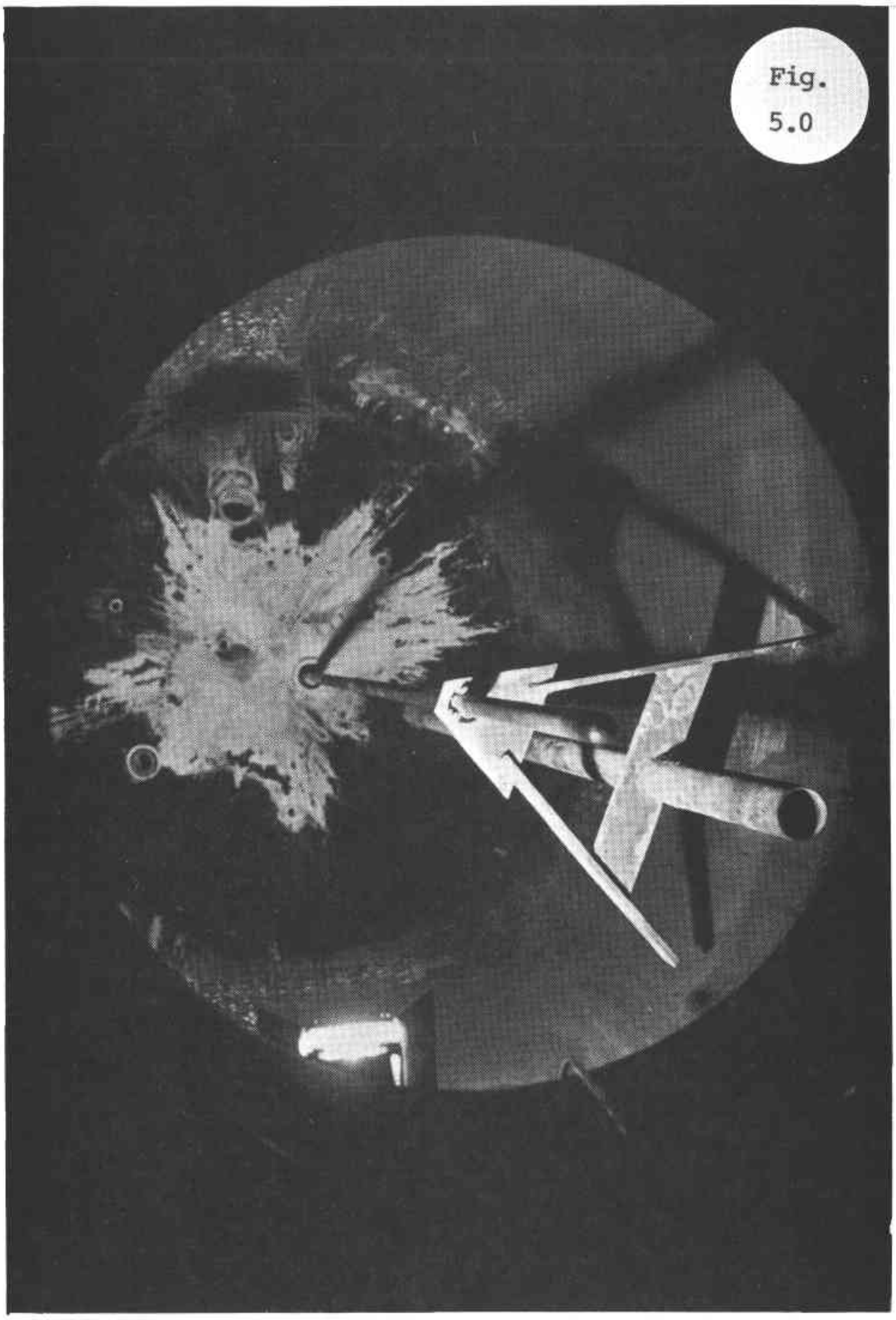


Fig. 5.0

Schartenstr 46
5430 Wettingen
Schweiz
27 March 1983

Herr Grasse,
Operating Agent for IEA.SSPS.
Apto 649
Almeria.

4 MAR. 1983
E713/83

Dear Herr Grasse,

I enclose the script that you requested for your report to the Executive Committee. I found that I had to write rather more than I expected because of the need to ensure that my comments were readily understandable. I trust that they meet your requirements.

I have enjoyed working with you and other members of the project and hope that I can find some way of keeping in touch with your future activities.

With best wishes,

Yours sincerely,

J Moore

Almeria CRS Plant

Status March, 1983

The report of the Expert Group, December 1982, identified potential reasons for sodium leaks and for problems with the Spilling engine. Also, it recommended actions to be taken.

* to clarify understanding of the reasons for these plant failures

* to bring the plant to an operating condition

* to improve plant operating procedures.

Now that the plant has been repaired and put into operation the following comments are relevant to the more important features of the work done and they record the opinion of the Chairman of the Expert Group on the effectiveness of the repairs and confidence in potential for future operation.

1. CAUSES OF SODIUM LEAKS

Of the potential causes for failure identified by the Expert Group the following have been eliminated following completion of tests recommended by the Group. Details of the tests are recorded in documents written by the TueV Cologne.

* temper embrittlement
* hydrogen

The state of understanding of the reasons for the cracks and their leading to sodium leaks is as follows:

1. 1] Cold Tank Bottom

* Initial cracking caused by bad design and originating in welds on the inside of the rails of the 'shock plate' that were difficult to make and inspect and could not be ground.

* Crack propogation due to these welds being hard and stressing the material to near the yield stress followed by stress cycling during operation.

* Failure of the 'dome' repair features due to continued growth of earlier cracks that had not been adequately stopped by drilling holes at their ends.

* Failure of patches on these leaks due to more growth of these cracks with some assistance from stress corrosion cracking caused by NaOH formed where sodium had contacted moist air before welding the patch.

A point of remaining uncertainty is evidence of some stress corrosion cracking that probably occurred before leakage throug the vessel and, therefore, before NaOH could be formed by sodium contacting moist air. Specific information from the history of manufacture, storage, installation and putting into operation of the vessel has not been found to explain this phenomena.

1. 2] Manhole Welds, Cold Tank and Regenerator Vessel

Cracking would be initiated from stress raisers such as crevice and discontinuities in the 'ragged' finish on the weld surface that was inside the vessels. This was due to

* inadequate welding with poor weld flow through to the inside surfaces of the materials being joined.

The degree to which the extent of cracking may have been affected by

* inadequate heat treatment

* any presence of moisture during the welding operation

has not been ascertained.

2. PRESENT STATUS

All zones associated with cracking and sodium leakage have been cut out of the plant and the two vessels, the cold tank and the regenerator vessel, have been inspected in detail to ensure that there are no further cracks.

During the various stages of the repair work TueV Cologne have very competently provided close surveyance and made control and acceptance checks in much greater detail than would be usual for industrial manufacturing operations.

2. 1] Cold Tank Bottom

The affected zone has been cut out and a patch welded into place as proposed by Interatom. Measurements have also been made of hardness and stress levels in metal with welds cut from the tank and in new weld test specimens that included welds joining old and new plates. These measurements were made in places of interest in the specimens relevant to assessing the state of the patch with its weld without having to drill or cut specimens from the repaired tank. The measurements indicated that in the finished patch with its weld there could be positions of

* metal hardness, and of

* stress levels

that could be near the recommended limits of acceptance without stress relieving. Relevant data is presented in Interatom and TueV records and reports.

Also, radiographs taken after making the root weld runs showed some places with porosity caused by inadequate manual weld control. These were cut out and repaired and the weld control deficiency corrected leading to no further problems with the following 'filler' weld runs.

All these operations were made within accepted engineering practices. Although design codes did not require this particular weld design to be stress relieved, the whole vessel was heat treated to stress relieve and so provide safety margins for

* hardness

* stress level

* compensation for the weld repairs.

Throughout these operations dimensional stability of the vessel was checked and at no time did it move outside the allowable limits. The small changes measured in straightness and roundness before and after welding and after heat treatment support the opinion that welding the patch in the vessel did not result in build-up of high stress levels.

From the detailed control data taken throughout these operations it is reasonable to conclude that the repair has been completely successful and it should not cause any problems during future plant operation.

2. 2) Manhole Weld, Cold Tank

The root weld runs showed defects similar to those for the tank bottom weld and so necessitated some cutting out and repair work. The weld was then completed with no further problems.

A modification to Interatom's original proposal was to leave a small diameter access port to enable inspection of the inside of the weld. This port also proved to be adequate to enable the inside of the weld to be ground before inspection.

The completed weld shows no flaws, it has been made within accepted engineering practices and it has been stress relieved. There is no reason to expect it to be a potential source of difficulties during future plant operation.

2. 3) Regenerator Vessel

The vessel was cleaned by vacuum distillation so enabling removal of all sodium without the use of water.

Inspection showed some cracks and a potential source of future cracking associated with an internal structural feature that had been welded to the inside of the vessel to restrain vibration of internal pipes during transport. These features were cut out and the surfaces inside the vessel ground. Inspection of the vessel and of these zones after grinding showed no cracks and no features presenting potential for future cracking.

The manhole weld was made in the same way as that for the cold tank manhole but with no difficulties and no need for any weld repair work. Inspection by access through the pipe at the bottom of the vessel showed the inside surface of the weld to be completely acceptable. In this case it was not possible to grind the inside surface. Finally the weld, but not the whole vessel, was stress relieved.

All operations were made within accepted engineering practices. No difficulties were met during the welding operations and there is no reason to expect any future operational problems with this vessel.

2. 4) Hot Sodium Tank

The hot sodium tank bottom with the 'shock plate' features was inspected using the most advanced ultrasonic methods for austenitic steel plates and welds. There was no evidence of cracking in the bottom of the vessel and the method proved to be sufficiently sensitive to identify irregularities on the surfaces of the welds that connect the shock plate rails to the bottom of the tank. It is known that irregularities must exist from the original welding process that could not be followed by grinding because of insufficient access to do so. The inspection method is not able to identify whether there are cracks associated with these irregularities.

The method of inspection proved to be more sensitive and to provide more information than was expected at the time the Experts Report was written last December. The information obtained was all in the direction of being reassured rather than less certain as to whether or not there was potential for failure by cracks and crack propogation. Accordingly there is no reason to change the judgement made in December that the tank should not be cut or opened and that it is reasonable to continue to operate.

2. 5) Thermal Shocks

Potential for thermal shocks in both the hot and cold sodium storage tanks has been reduced by fitting flow distributors in the sodium inlet pipes as proposed by Interatom. Also, the specification for plant operation has been modified to increase the minimum level of sodium so increasing the volume of sodium available to reduce the magnitude of thermal cycles caused by flow of sodium into the tanks.

The Expert Group report in December included comment that the overall plant and plant components were designed to be able to accept the thermal cycling that had been measured and calculate except for the shock plate features in the cold and hot sodium storage tanks. It recommended that it would be prudent to reduce thermal shocks where practicable.

Steps have been taken to reduce thermal shocks and the planned method of operation should maintain plant conditions within acceptable design limits. However, it would be sensible to continue to be aware that it is desirable to avoid unnecessary thermal cycling during future plant operation.

3. SPILLING ENGINE

The recommendations of the Expert Group have been implemented. In particular arrangements for drainage and avoidance of water entering the engine cyclinders have been examined in detail.

Orifices have been fitted to condensate return pipes that run from the condenser to the evaporator section in each evaporator. This has improved control of liquid levels in the evaporator and the plant now regenerates water effectively when on load and no longer continuously loses water.

The engine has since operated satisfactorily at 80% load factor and there are no known reasons for expecting continued difficulties. The recommendation to limit load factor to 80% has no specific technical basis: it was judged reasonable to apply such a limit until operator confidence warranted an increase. There is no reason to change that judgement - the plant operators should increase load factor when they judge it reasonable to do so.

A satisfactory arrangement has been made for the Spilling representa tive to stay on site until the end of the year. Recommendations relevant to maintenance and training are being implemented.

4. FUTURE INSPECTION

Confidence in the repairs to the sodium vessels is such that it is not considered necessary to plan for an early inspection to check that no further weaknesses are developing.

In planning when next to inspect it is necessary to take into accoun that

* Funding may limit plant life to the end of 1983
* Interatom have guaranteed the repaired vessels for two years
* there will be statutory requirements for inspection.

Clearly any statutory inspection requirements will have to be met and if the plant is to continue operation after this year it would be wise to inspect the repairs to the vessel before the Interatom guarantees run out. Otherwise it is more important during the rest of this year to ensure maximum use of the plant than to interfere with operation by making further inspection of the repairs. However, if there are any significant breaks in operation then the plant operators may wish to take the opportunity to check, as convenient, some of the repairs.

J. Moore
Chairman, Expert Group

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		P. KESSELRING	(CH)
		C.J. WINTER	(D)
		M. FISCHER	(D)
		W. HOFMANN	(D)
		A. MUÑOZ TORRALBO	(E)
		C. ORTIZ	(E)
		CH.ARONIS (E. CARABATEAS)	(GR)
		G. ELIAS	(I)
		F. REALE	(I)
		G. BEER	(I)
		L. BRANDELS	(S)
		J. HOLMBERG	(S)
		L. GUTIERREZ	(USA)
		C. SELVAGE	(USA)
2)	IEA - SECRETERIAT	L. BOXER	
3)	B M F T	H. KLEIN	
4)	C E E	I. MARTIN	
5)	SANDIA LABORATORIES	A. BAKER	(3 x)
6)	D F V L R	R. KÖHNE	(3 x)
7)	OPERATING AGENT	M. BECKER	
		W. BUCHER	
		H. ELLGERING	
		W. GRASSE	
		P. HEINTZELMANN	
		H. HERTLEIN	
		A. KALT	
		W. VON KRIES	
8)	INTERNATIONAL TEST & EVALUATION TEAM	C. SELVAGE	(20 x)
9)	SEVILLANA	F. RUIZ	(3 x)
10)	MOTOR COLUMBUS	J. MOORE	
11)	ETEC	N. HOFFMAN	
12)	EIR	H. KOHL	
13)	BBC	A. SCHWARZENBACH	
14)	TÜV	ADAMSKI, WILTERS	(5 x)
15)	RWE	SCHWARZ	
16)	ACUREX CORP.	A. F. SCHRAUB	
17)	BELGONUCLEAIRE	G. DEBIER	
18)	INTERATOM	B. FLOSS / D. STAHL	
19)	MAN - NEUE TECHNOLOGIE	J. FEUSTEL	
20)	MARTIN MARIETTA CORP.	C. WROTON	
21)	AGIP NUCLEARE	G. C. SCARPI	
22)	FRANCO TOSI	V. BEDOGNI	

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