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Test manufacturing of copper canisters with cast inserts

Assessment report

Claes-Göran Andersson

Svensk Kärnbränslehantering AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Information on SKB technical reports from1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01), 1985 (TR 85-20), 1986 (TR 86-31), 1987 (TR 87-33), 1988 (TR 88-32), 1989 (TR 89-40), 1990 (TR 90-46), 1991 (TR 91-64), 1992 (TR 92-46), 1993 (TR 93-34), 1994 (TR 94-33), 1995 (TR 95-37) and 1996 (TR 96-25) is available through SKB.

Summary

The current design of canisters for the deep repository for spent nuclear fuel consists of an outer corrosion-protective copper casing in the form of a tubular section with lid and bottom and an inner pressure-resistant insert. The insert is designed to be manufactured by casting and inside are channels in which the fuel assemblies are to be placed.

Over the last years, a number of full-scale manufacturing tests of all canister components have been carried out. The purpose has been to determine and develop the best manufacturing technique and to establish long-term contacts with the best suppliers of material and technology. Part of the work has involved the developing and implementing of a quality assurance system in accordance with ISO 9001, covering the whole chain from suppliers of material up to and including the delivery of assembled canisters.

This report consists of a description of the design of the canister together with current drawings and complementary technical specifications stipulating, among other things, requirements placed on different materials. The different manufacturing methods that have been used are also described and commented on in both text and illustrations.

For the manufacturing of copper tubes, the roll-forming of rolled plate to tube halves and longitudinal welding is a method that has been tested on a relatively large number of tubes by now, and that probably can be developed into a functioning production method. However, the very promising outcome of performed tests on seamless tube manufacturing, has resulted in a change in direction in tube manufacturing, focusing on continued testing of extrusion as well as pierce and draw processing in the immediate future. In connection with ongoing operations, new manufacturing tests of tubes with less material thickness will be carried out. (30 mm for an assembled canister.)

Test manufacturing of cast inserts has resulted in the choice of nodular iron as material in the continued work. This improvement in design has resulted in a more even distribution of material inside the inserts. The change will reduce the risks for casting defects in the material, and is therefore considered to be a quality-improving measure. Continued test castings of inserts in nodular iron for both BWR and PWR fuel assemblies will be undertaken during the immediate coming years.

In future production, empty canisters will be manufactured at a special factory and transported from there to the encapsulation plant. A preliminary study regarding the design of such a factory has been carried out.

During the rest of 1998 and 1999, 8–9 complete canisters will be assembled for use in different projects in the Äspö Hard Rock Laboratory. These projects will complement experiences made in the entire manufacturing process.

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1 Introduction

In accordance with the KBS-3 method, the current design of canisters for the deep repository for spent nuclear fuel consists of an outer copper casing in the form of a tubular section with lid and bottom and an inner pressure-resistant component, the insert. The insert is designed to be manufactured by casting and inside are channels in which the fuel assemblies are to be placed.

Over the last years, a number of full-scale manufacturing tests of both copper tubes with lid and bottom, as well as cast inserts, have been carried out – figures 1-1 and 1-2 – and continued manufacturing is planned for the immediate coming years.

This serves several purposes. Full-scale test manufacturing results in experiences that provide possibilities to test different manufacturing methods in order to determine and develop the most suitable manufacturing technique. In addition, a survey and assessment of accessible suppliers is being carried out in order to establish long-term contacts and find the best suppliers of material and technology. A quality assurance system in accordance with ISO 9001 is also being developed and implemented, that will cover the whole manufacturing process from suppliers of material up to and including the delivery of assembled canisters. A number of canisters will be completed during 1998 and 1999 for usage in different projects at the Äspö Hard Rock Laboratory with the purpose of testing and demonstrating deep repository technology.

In FUD 95 (in the following RD&D 95), reference [1], there is an extensive outline of the background to the current manufacturing programme during the years 1996–1998, describing the design of the canister, the motives behind choice of materials and comments on alternative manufacturing techniques.

An earlier report, [2], includes results from initial test manufacturing mainly carried out during 1995. At the time, the design of the canister was different. The pressure-resistant insert was not manufactured by casting, instead it was designed as a steel tube made out of rolled plate or by extrusion. The diameter of the canister was also shorter than it is in the design of today.

The aim of this report is to account for results from the continued test manufacturing carried out during 1996 and up until August 1998. The report also provides the basis for the continued programme for further development of the canister technique as described in FUD 98 (RD&D 98).

Figure 1-1. *Test manufacturing of canisters. The picture shows a copper canister with a cast insert, a copper lid and some exhibits.*

Figure 1-2. *Test manufacturing of canisters. The picture shows copper tubes and inserts. Two of the copper inserts have welded-on bottoms.*

2 The canister – design and choice of materials

2.1 General description

The manufacturing and development programme accounted for in this report is based on the description in RD&D 95, reference [1].

A recently published report, reference [3], presents a detailed background to the current design of the canister, including a summary of the dimensioning criteria and the motives behind the choice of materials.

Figure 2-1 shows the basic design of the canister. It consists of an outer corrosion barrier in copper in the form of a tube with lid and bottom, and an inner pressure-resistant component, the insert. The insert is manufactured by casting and is equipped with channels in which the fuel assemblies will be placed. A steel lid covers the channels at the top of the insert. It shall be possible to use the canister for both BWR and PWR fuel from the Swedish nuclear power programme. The insert in figure 2-1 is designed with 12 channels for BWR fuel assemblies.

In the case of PWR fuel assemblies, the insert is designed to hold 4 fuel assemblies. Figure 2-2 shows cross sections of both designs equipped for 12 and 4 fuel assemblies respectively.

The diameter of the copper canisters is 1050 mm. The length has been set at 4830 mm. With a wall thickness of 50 mm for the copper casing and a cast insert in nodular iron, the total weight of the canister without fuel assemblies included, is approximately 21 400 kilos for the 12-channel version and approximately 24 300 kilos for the 4-channel version.

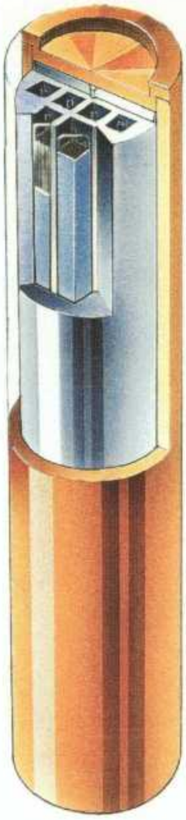

Figure 2-1. Copper canister with cast insert in which 12 BWR fuel assemblies can be placed.

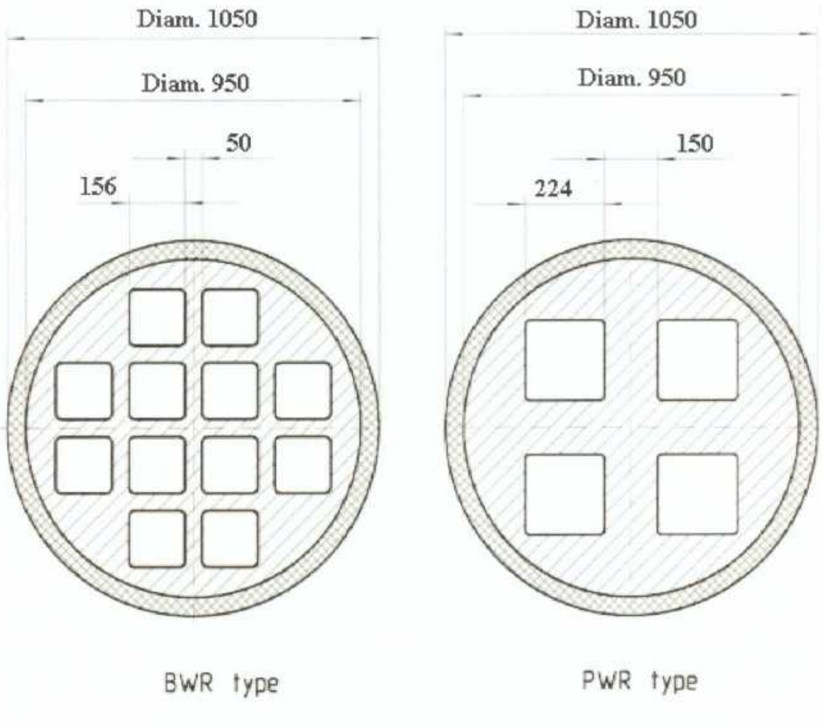

Figure 2-2. Cross section of canisters in which 12 BWR fuel assemblies and 4 PWR fuel assemblies respectively, can be placed.

For the different manufacturing tests that have been carried out, a system of various detailed drawings have gradually been produced. Appendix 1, consisting of a complete set of drawings for a canister with a nodular iron insert with 12 channels for BWR fuel assemblies, is shown as an example. The continuous development of drawings and specifications is done with the frame of the quality assurance system for canister manufacturing. This system is described in more detail in chapter 6.

2.2 Copper tubes with lid and bottom

The current manufacturing technique for the copper casing consists of either copper plate rolled into tube halves that are then welded together into tubes by means of longitudinal electron beam welding (EB welding), or by manufacturing seamless tubes by extrusion of copper ingot. The copper lid and copper bottom are machined out of pre-formed press-forged material.

For copper components manufactured in accordance with any of the above methods, a technical specification, KTS 001, stating current material requirements, has been put together, see appendix 9. In short, the special copper quality specified is described as pure oxygen-free copper with an addition of approximately 50 ppm phosphorus. As stated in KTS 001, the material has no exact equivalent in either Swedish or international standards. A high level of purity from pollutants is favourable from a corrosion point of view. The addition of phosphorus has proved to be favourable for creep ductility when subjected to creep testing. The copper casing must be able to withstand a small percentage of deformation since a gap of about 1 millimetre between the copper casing and the copper tube will have to be allowed due to manufacture-technical reasons. Due to stress in the deep repository, the copper casing will eventually become deformed against the insert. A more detailed argument regarding material requirements can be found in reference [3].

Apart from strictly material requirements, KTS 001 also specifies that inspections upon delivery and documentation requirements be met in the form of certificates.

2.3 Insert and insert lid

In the current manufacturing programme, inserts are manufactured by casting with channels for fuel assemblies. During the development work, test casting has been performed in both cast steel and nodular iron. In chapter 4, detailed results from these tests are reported. Nodular iron has been chosen as material in the prototype canister partly because of its better castability qualities.

Two technical specifications have been developed for cast inserts: KTS 011 for nodular cast iron SS 140717 inserts, appendix 10, and KTS 021 for the welded cassette manufactured in steel profiles which are cast into the nodular iron thus forming the channels in which the fuel assemblies are placed, appendix 11. See also chapter 3 below.

The steel insert lid is manufactured in construction steel SS 141312, or equivalent foreign standard, in accordance with drawings 00003-21/00 and 00003-211/00 as specified in appendix 1.

3 Manufacturing techniques – overview

3.1 General

In RD&D 95, reference [1], 5 different possible manufacturing methods were described for the **tube-formed section of the copper canister**:

- Rolling/Roll forming into tube halves welded together by longitudinal welding seams
- Extrusion of tubes
- Hot Isostatic Pressing, HIP
- Spray forming
- Electrodeposition

Of these methods, only the first two have been tested in full scale. Extrusion is a method for the manufacturing of tubes without longitudinal welding seams. An alternative to extrusion is pressing and the pulling over mandrels to required dimensions. We can call this technique pierce and draw processing. Today, all these alternatives, roll-forming, extrusion and pierce and draw processing, are established industrial methods used for manufacturing tubes in dimensions equivalent to the SKB canister tube dimensions. There are a number of available suppliers in Europe that can conduct test manufacturing with these methods. The major part of extrusion and pierce and draw processing production today, deals with the manufacturing of tubes in more or less alloyed steel, often for demanding use in nuclear power plants or in the off-shore industry. However, before SKB initiated test manufacturing, there was no, or insignificant, experience in the test manufacturing of copper tubes in the current canister dimensions.

None of the other three methods have come into question for full-scale testing. These methods have only been analytically studied or tested on a small scale in a laboratory environment. Therefore, the current situation regarding these methods is presented in a separate chapter, chapter 5.

Copper lids and bottoms are machined from material that has been preformed by forging. The forging results in a form of material that enables a lesser amount of material to be machined off, but it also results in the material gaining a better (finer grain size) structure and also increased strength. Forged blanks for lids and bottoms can be produced by suppliers in the Nordic countries, but also by suppliers in other European countries.

The **current welding technique** for longitudinal welding of tube halves and fix-welding of bottoms used for the manufacturing of the canisters, is the electron beam welding technique (EB welding). The seal-welding of the copper lids on canisters filled with spent nuclear fuel, is also planned to be performed by means of EB welding at the future encapsulation plant. The technique used for seal-welding will be tested at SKB´s Canister Laboratory in Oskarshamn. The EB welding will be carried out in a welding chamber under conditions of partial vacuum or high vacuum. SKB has developed this special technique for welding of copper canisters together with The Welding Institute (TWI) in England. By exclusive license agreement, SKB has also obtained sole right to the technology for this specific use, subject to TWI's patent.

For the manufacturing of **inserts** in steel casting or nodular iron, there are a number of available foundry suppliers in the Nordic countries. Several of these currently produce cast products in the same size as, or of considerably larger size than, the canister inserts. The materials that have hitherto been tested in inserts, steel casting SS 141306 and nodular iron SS 140717, are both standard grades well-known within the industry, and of which there is extensive experience.

A preliminary evaluation of the design of a future factory for canister manufacturing, describes the current manufacturing methods, reference [4]. An information video has also been produced, reference [5], showing, among other things, different stages in the manufacturing chain.

3.2 Current manufacturing techniques for copper tubes, roll-forming, pierce and draw processing and extrusion

3.2.1 Roll-forming of tube halves and longitudinal welding

The basic material used in roll-forming is hot-rolled copper plate, in accordance with the technical specification KTS 001, see appendix 9.
For the manufacturing of a tube in accordance with the current design as shown in drawing 00001-111/00 in appendix 1, two rolled plates measuring 60x2000x4900 mm are used. Figures 3-1 and 3-2 show the roll-forming of tube halves in two different machines.

Figure 3-1. *Roll-forming of a short copper tube.*

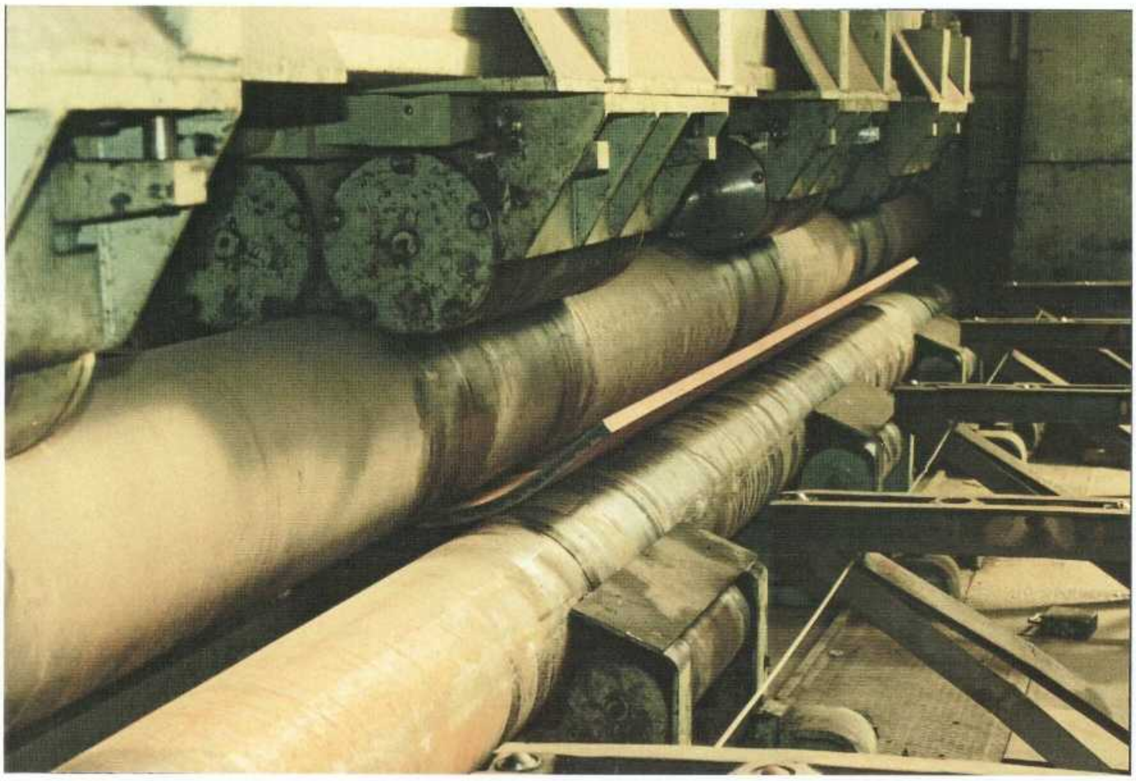

Figure 3-2. *Roll-forming of a full-length copper tube.*

The technique of roll-forming is, to an extensive degree, a manually regulated cold-forming process that places high requirements on the skills of the operators. The forming is done in stages and the shape of the tube halves is controlled against templates between each step until the result is satisfactory and fulfils requirements as outlined in drawing 00001-1111/00 in appendix 1.

After forming, the tube halves end up with surplus measurements that need to be removed, figure 3-3. This machining is followed by a milling operation that, at the same time, prepares the seams for longitudinal welding. After the final inspection of the tube halves' measurements, the tube halves are fitted together in a fixture, figure 3-4, and thereafter the EB welding is carried out in the vacuum chamber, figure 3-5. All EB welding of canister components that have hitherto been carried out have been performed at TWI in England.

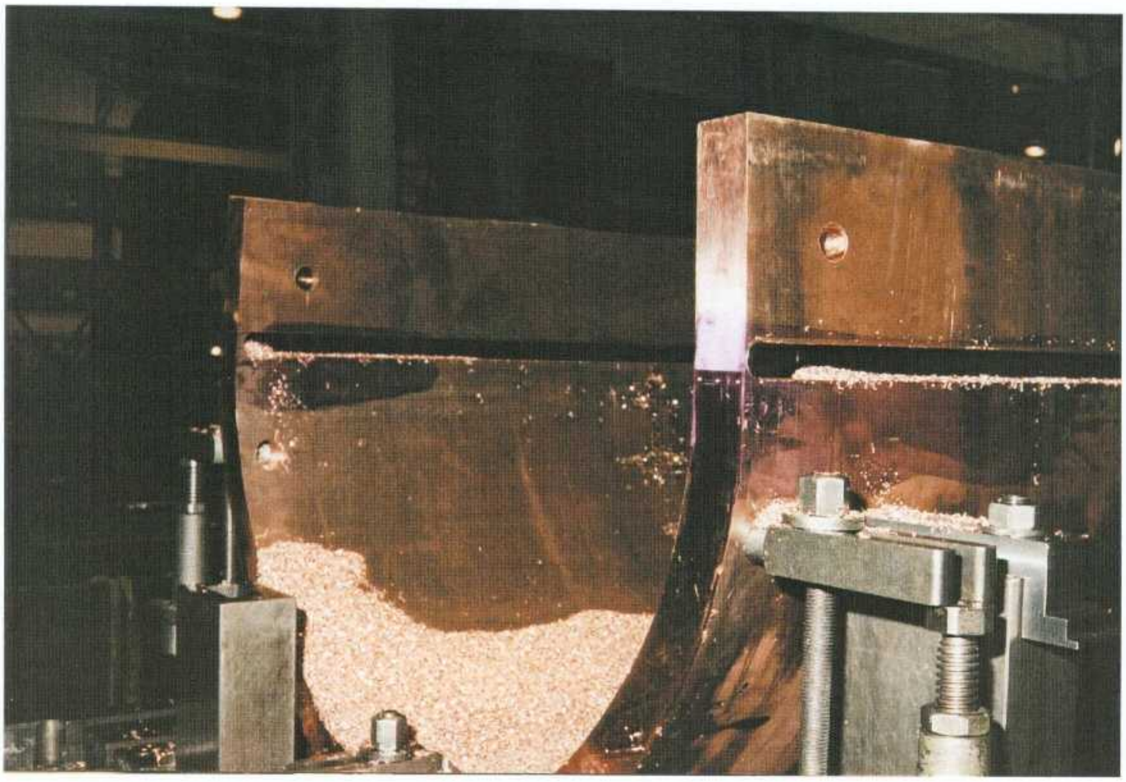

Figure 3-3. *Machining of surplus measurement on roll-formed tube halves.*

***Figure 3-4.** The putting together of tube halves for electron beam welding. The copper bars in the middle have been placed there in order to prevent the opposite wall from being hit by the electron beam during the longitudinal welding.*

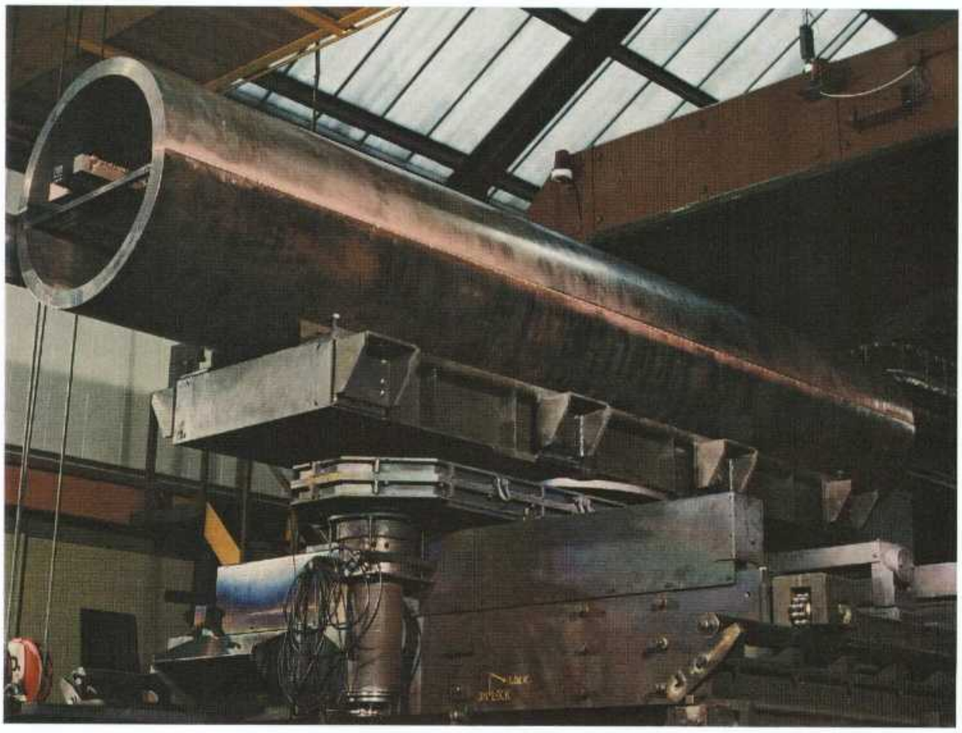

***Figure 3-5.** The vacuum chamber for electron beam welding. The photo shows a welded copper tube at the opening of the vacuum chamber.*

After the longitudinal welding has been carried out, the tube has to be stress-relief annealed after machining in order for residual stress to be removed, which could otherwise cause changes in its shape. All stress-relief annealing carried out during current test manufacturing, has been done in the same chamber furnace in the following way:

- The tubes have been placed in the furnace at a temperature of 250–300 °C. The holding time at this temperature has been approximately 3 hours.

- The temperature has been increased by 50 °C per hour up to 400 °C. Holding time 4 hours.

- The tubes undergo a slow cooling process in the oven down to 100 °C.

After the stress-relief tempering has been done, machining on both the insides and outsides of the tubes is carried out. Figure 3-6 shows the setting up of a copper tube for internal drilling in a machine.

Figure 3-6. *Internal drilling of a copper tube.*

3.2.2 Pierce and draw processing of copper tubes

Pierce and draw processing is one of the two methods identified for use in seamless manufacturing of copper tubes. At Vallourec & Mannesman in Germany, SKB has been given access to a production facility in which full-scale test manufacturing can be carried out. Figure 3-7 describes the basis of the method that, unlike the technique of roll-forming described in the previous section, is a hot-forming process. The basic material used is a cylindrical copper ingot in an adjusted size. The material is first hot-formed by upset forging, which gives a shorter material with larger diameter, and is then placed in a special tool in which it is pierce-punched, see the left-hand illustration in figure 3-7. The bottom part of the material is kept intact in order to support the piercers during the continued forming, which is done in several steps in accordance with the right-hand illustration in figure 3-7.

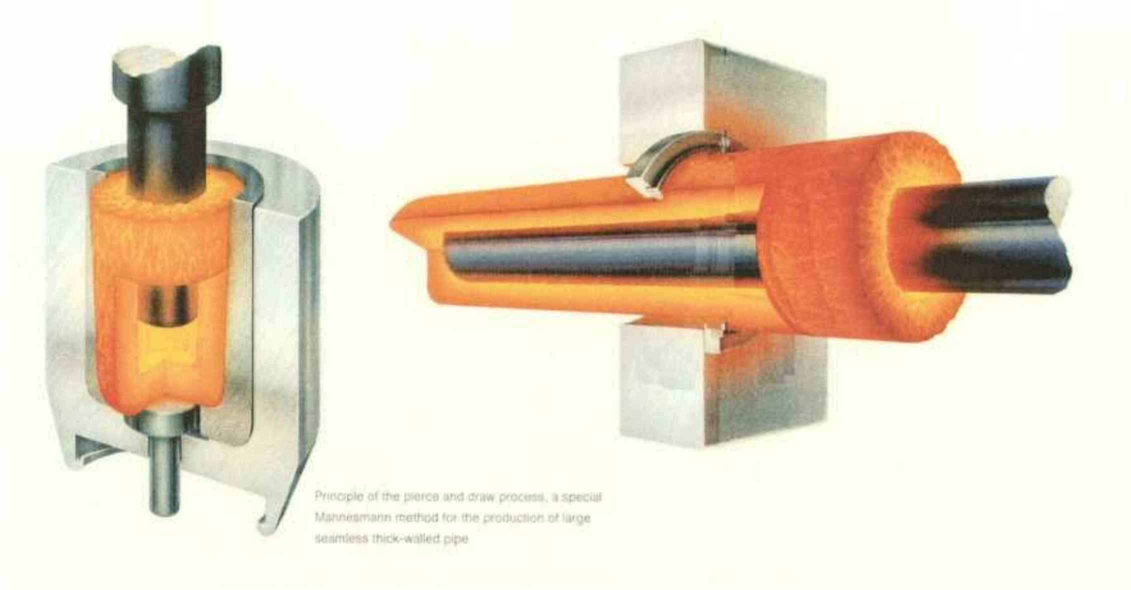

Figure 3-1*. Seamless tube manufacturing with pierce and draw processing. (Vallourec & Mannesmann)*

The forming results in the gradual increase of the inner and outer diameters of the SKB copper tubes until they have obtained the required final dimensions. This is done by successively changing the piercers and the outer ring through which the tube material is pressed as shown in figure 3-7. The tool measurements are adjusted to enable the gradual decrease of the wall thickness of the tube while, at the same time, the length of the tube is increased. Between each forming stage, the tube material is re-heated to the required temperature. In the information video about canister manufacturing produced by SKB, reference [5], a sequence shows how the tubes are manufactured using this technique.

After the final forming stage has been completed, the material is allowed to cool. After having cooled, both ends of the tube are cut off to meet length requirements. At this stage then, the remaining bottom part is removed. According to the assessment of SKB, no stress-relief annealing is needed in this process.

The last stage in this manufacturing process of copper tubes, is the inner and outer machining to obtain the final measurements. See figure 3-6.

Whether or not the bottom part that forms part of the process technique could be left on the tube and, after the machining has been completed, be used as the bottom in the copper canister, has been discussed. Vallourec & Mannesmann manufacture special canisters in this way. However, we would face several problems in following their practice. First, the process has to be carried out ensuring that the material in the bottom is hot deformed in such a way that a structure with the required grain size is obtained. Second, the inner machining of this relatively long tube with integrated bottom would probably be difficult to manage. Future work will show whether or not this will be an alternative.

3.2.3 Extrusion of copper tubes

The second method identified for use in seamless manufacturing of tubes is extrusion. Extrusion tests have been undertaken earlier by SKB, and the results are presented in reference [2]. As far as we know, Wyman Gordon Ltd, with facilities in Scotland and USA, is the only company with presses large enough, (30 000 tonnes press power), to manage extrusion of tubes in the dimension required.

Extrusion is, like pierce and draw processing, a hot-forming method. The basic material, here too, is a cylindrical copper ingot of an adjusted size, see figure 3-8.

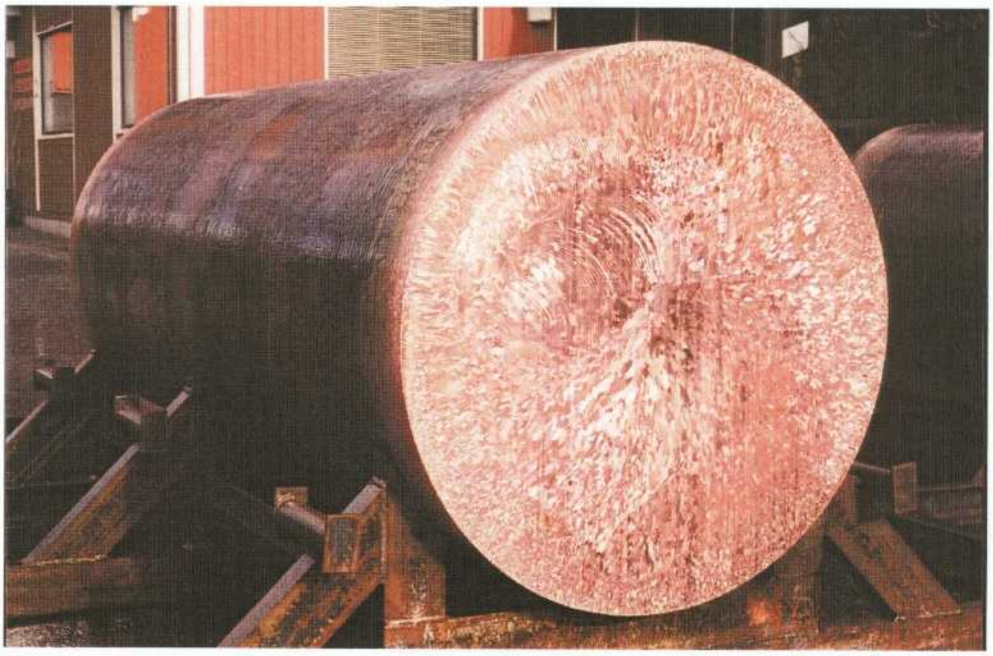

Figure 3-8. *Copper ingot for extrusion.*

Figure 3-9 shows the principles involved in the first stage of the process. The ingot is heated and by upset forging, in a two-step procedure, in a smaller press, formed into a cylinder that is then punched into a hollow blank for extrusion. Figure 3-10 is a photo of a punched blank.

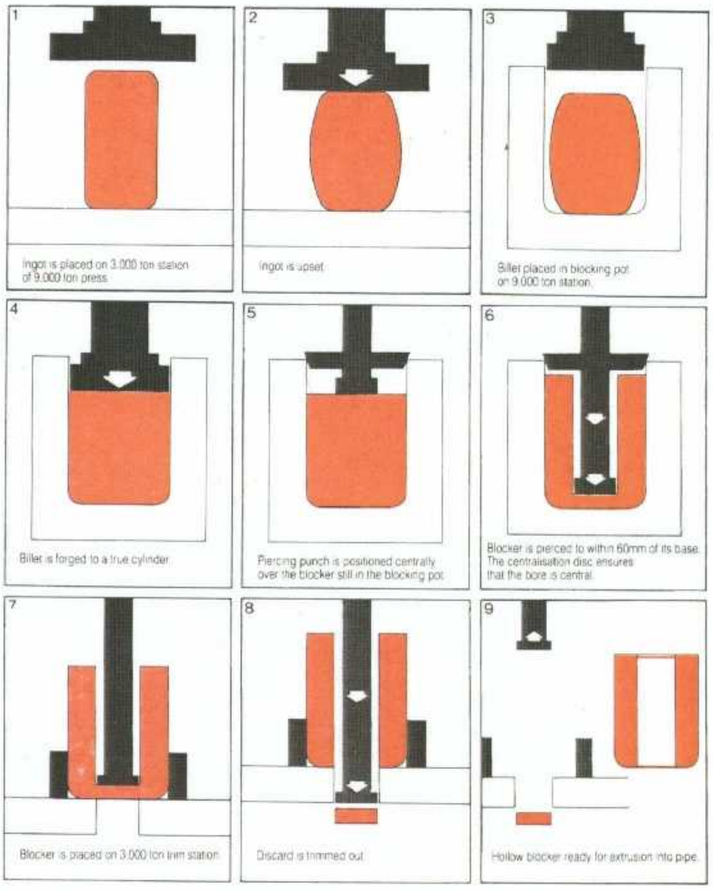

Figure 3-9. *Stage 1 in the extrusion process. Upset forging and punching of copper ingot to a blank for extrusion.*

Figure 3-10. *Photo of a punched blank ready for extrusion.*

The principle of extrusion in a 30 000-tonnage press is illustrated in figure 3-11. The punched blank is heated to the required temperature and placed in a position under the press tool in accordance with the figure at the top left. An internal mandrel determines the inner diameter. The large press tool is pushed downward and the tube is formed and pressed in a vertical upward single motion until the required dimension is reached.

After extrusion, the finished tube cools to indoor temperature. As in the case of pierce and draw processing, the assessment has been made that tubes manufactured in this way do not have to be stress-relief annealed before final machining.

Figure 3-12 is a photo of extrusion-processed copper tubes.

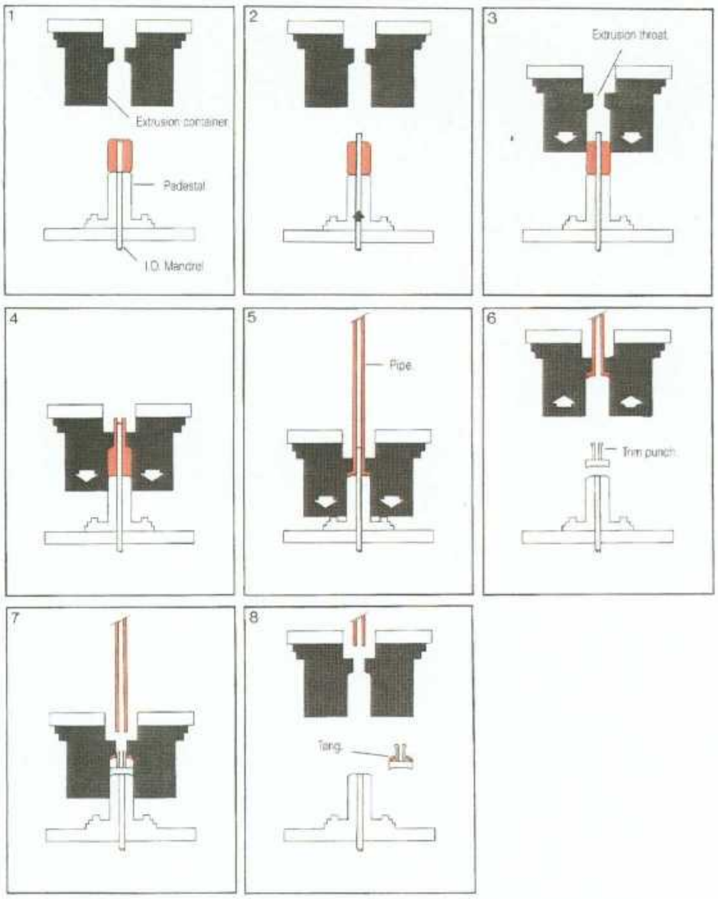

Figure 3-11. *The principle of extrusion of a punched blank. The extrusion-processed tube is pressed upward in a vertical motion when the press tool is pushed downward.*

Figure 3-12. *Extrusion-processed copper tubes. As with pierce and draw processing, the last stage in the manufacturing of copper tubes using this method, is the inner and outer machining.*

3.3 Manufacturing of cast inserts

The design of the cast inserts has been described above in chapter 2. The inserts are cast with 12 channels for BWR fuel assemblies, and with 4 channels for PWR fuel assemblies.

When casting inserts in steel casting or nodular iron, the channels are made with the use of steel pipes with square profiles that are cast into the material. The design can be seen in drawings 00004-12/00 and 00002-1211/00 in appendix 1. The profiles are welded together to a cassette that is placed in the centre of the casting mould and then cast into the insert.

Figure 3-13 shows a welded cassette before being placed in the casting mould.

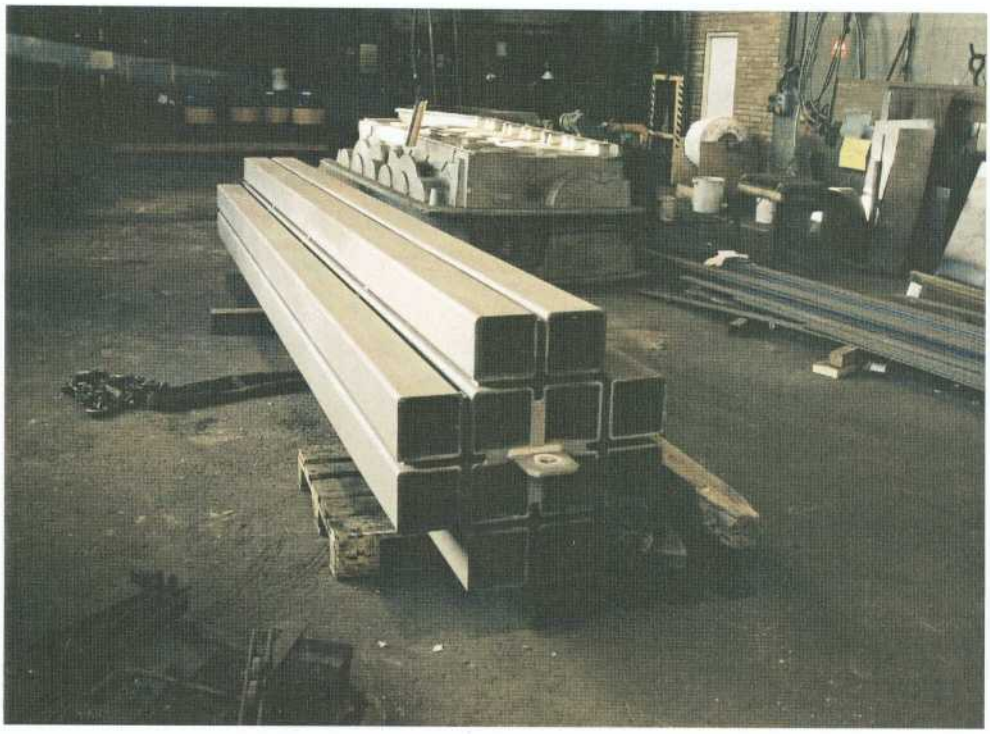

Figure 3-13. *Welded cassette with 12 channels for BWR fuel assemblies.*

Before casting, the open channels in the cassette are filled with sand, figure 3-14. This is necessary in order to avoid inward deformation of the profile walls under pressure from the melt during casting. Figure 3-15 shows a photo of a nodular iron casting that has been carried out.

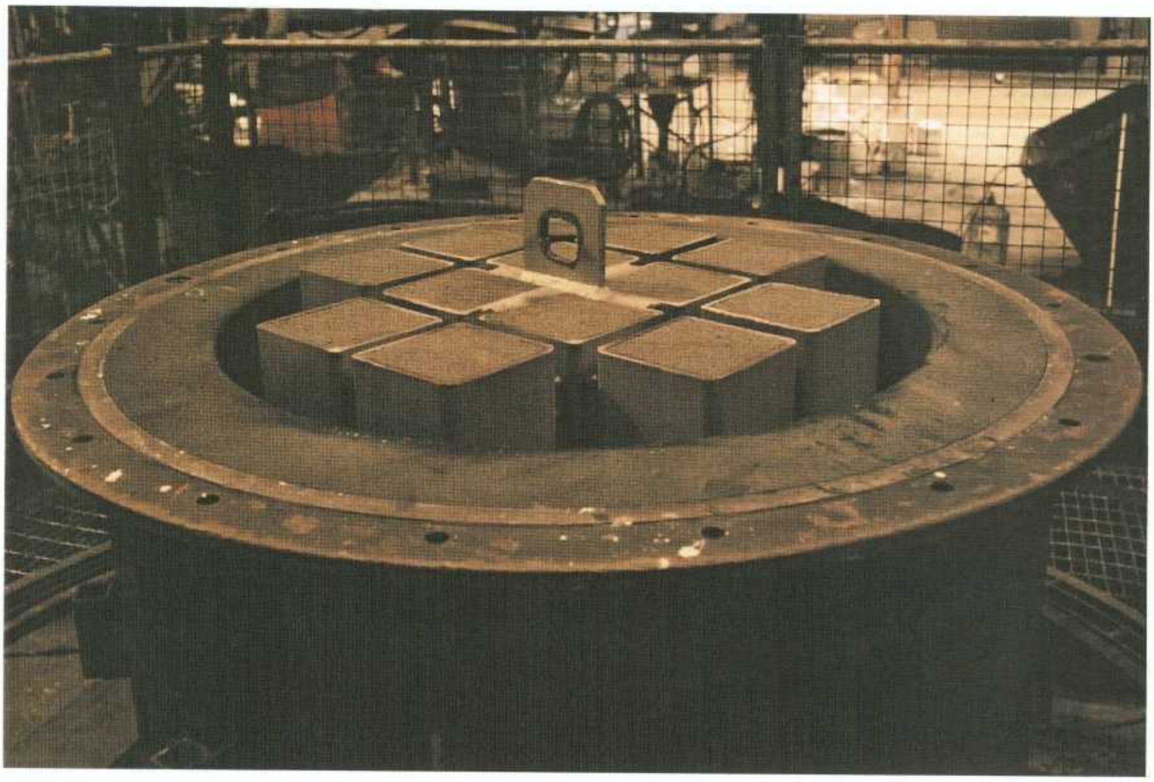

***Figure 3-14**. Welded cassette in the casting mould. The channels have been filled with sand in order to withstand the outer pressure of the molten bath.*

***Figure 3-15**. Casting of insert.*

After having cooled in the mould, it takes a few days since the cast material weighs approximately 15 tonnes, the casting is knocked out and can then be machined.

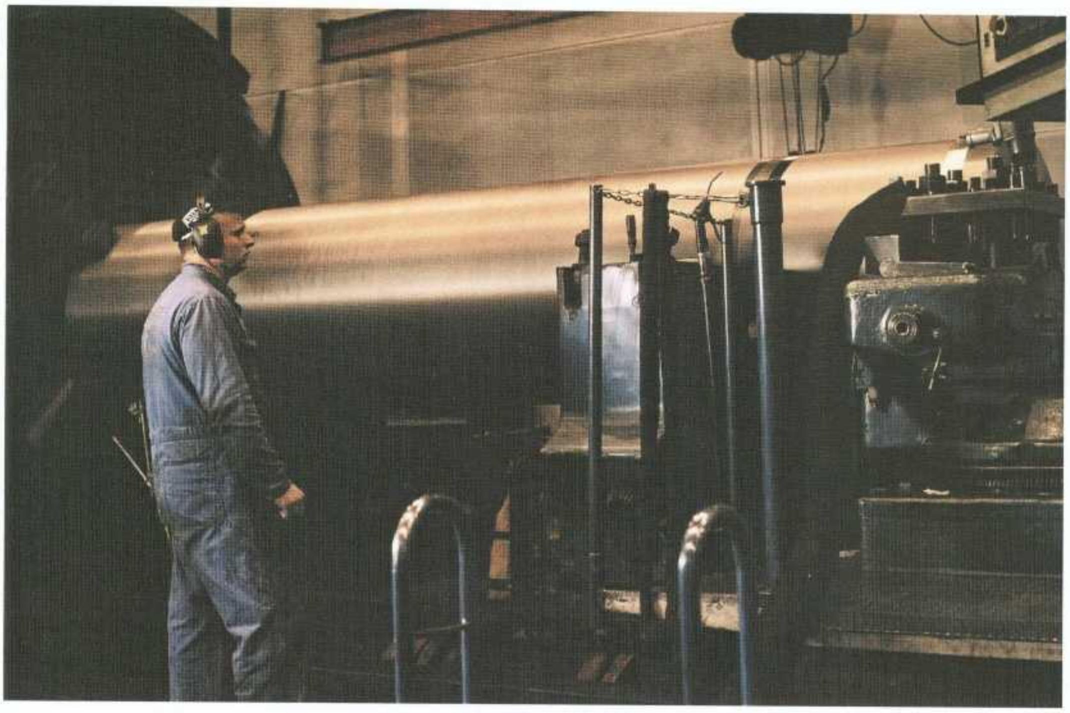

***Figure 3-16**. Turning of cast insert in nodular iron.*

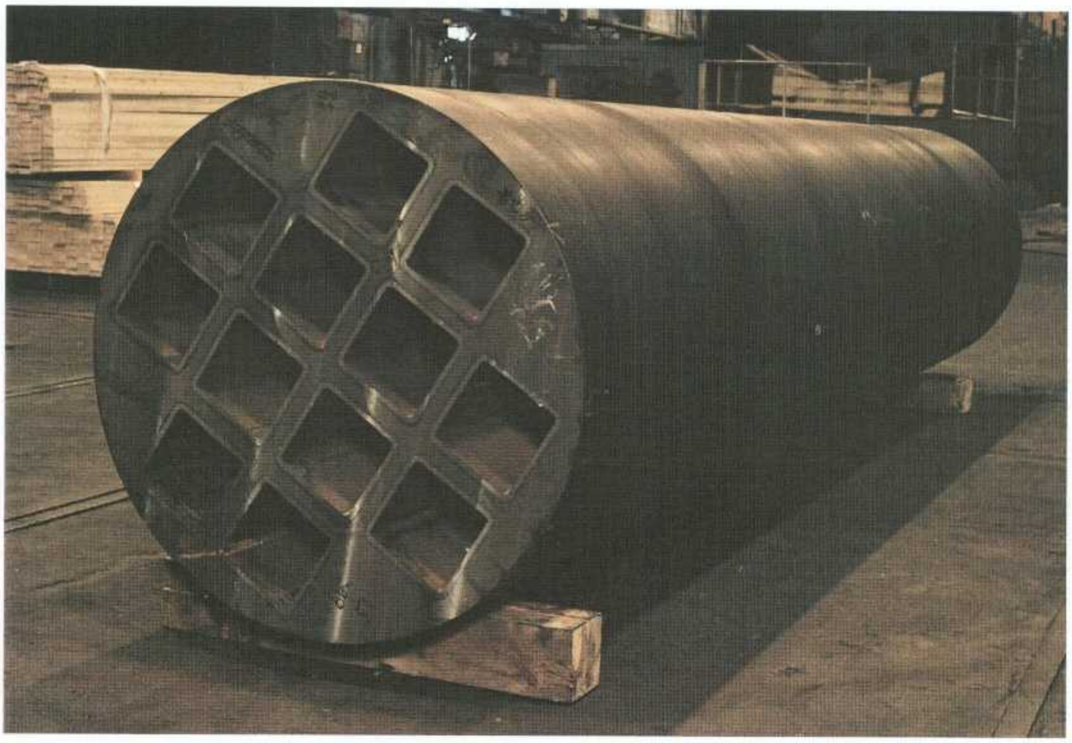

***Figure 3-17**. Nodular iron insert after turning of the outer surface as seen from the upper section of the insert. The machining of the top, forming the mounting for the steel lid, remains to be done.*

4 Test manufacturing results

4.1 General

The results of test manufacturing carried out during 1994 and 1995 were reported in an earlier study [2]. The design of the pressure-resistant insert has been changed since then. At that time, the pressure-resistant insert was not manufactured by casting, instead it was manufactured as a steel pipe formed from rolled plate or by extrusion. The outer diameter of the canister was also smaller, 891 mm instead of the 1050 mm of the current design. The copper tubes were test manufactured in part by roll-forming and longitudinal welding (2 ea.) and in part by extrusion (2 ea.)

The quality assurance system for canister manufacturing already mentioned, and which is described in more detail in chapter 6, was applied from the beginning of 1997, and has thereafter been developed incrementally. As described in chapter 6 and appendix 8, a serial number system was introduced for the different parts of the canister and for completely assembled canisters. For purposes of identification and traceability, all manufactured components are given a unique serial number in accordance with the following principle:

Component	**Identification number**
Copper tubes	T 1, T 2, T 3, etc.
Bottoms for copper tubes	TB 1, TB 2, TB 3, etc.
Lids for copper tubes	TL 1, TL 2, TL 3, etc.
Inserts for BWR fuel assemblies	I 1, I 2, I 3, etc.
Lids for inserts	IL 1, IL 2, IL 3, etc.
Assembled canisters	C 1, C 2, C 3, etc.

The serial numbers are mechanically stamped onto the component in accordance with procedure description KT 0705 in appendix 8, and in the place so indicated on the drawing, see drawing 00001-112/00 in appendix 1, for example. These identification numbers have been used below in the presentation of the results from test manufacturing.

An overview of canister components manufactured during the period 1996–1998 is given in table 4-1. The results of these manufacturing tests are reported in more detail under the respective heading.

Table 4-1. Summary of canister component manufacturing during 1996–1998.

Component	Manufacturing method	No. manufactured 1996–1998	Planned manufacturin 1999
Copper tubes	Roll-forming from rolled plate	10	–
Copper tubes	Dornpressning	1	2–3
Copper tubes	Extrusion	3	3–5
Lids and bottoms in copper	Forging and machining	42	approx. 30
BWR inserts	Steel casting	1½	–
BWR inserts	Nodular iron	7	6
PWR inserts	Nodular iron	1	2
Lids for inserts	Machining from rolled steel plate	3	approx. 10

4.2 Manufacturing of copper tubes

4.2.1 Roll-forming of rolled plate and longitudinal welding

A general survey of copper tubes manufactured in this way since 1996, is presented in table 4-2. Copper tubes with identification numbers T 1 and T 2 manufactured in this way, have been described earlier in reference [2]. T 2 is part of the exhibition canister with the identification number C 1.

Table 4.2. Survey of the manufacturing of copper tubes by roll-forming and longitudinal welding.

Identification number	Comments
T 5	Rolled plate 65x1700x5000 mm designed for the earlier canister design with Do = 891 mm. Some shorter tubes were manufactured from this type of plate for exhibition usage, the two short tubes in figure 1-1, for example.
T 6	Rolled plate 65x1850x4900 mm. Machined to Di = 950 mm and Do = 1050 mm, i.e. wall thickness 50 mm.
T 7	Rolled plate 40x2000x4900 mm. Test with 40 mm plate. Machined to Di = 952 mm and Do = 1010 mm, i.e. wall thickness 29 mm.
T 8–T 11	Rolled plate 60x2000x4900 mm. Machined to Di = 952 mm and Do = 1050 mm, i.e. to wall thickness 49 mm. The same measurements as in the 00001-111/00 drawing in appendix 1. T 8 is part of the exhibition canister that has a bevel-cut upper section, and is exhibited in the office pavilion at the Äspö Hard Rock Laboratory.
T 12–T 15	Rolled plate 60x2000x4900 mm. Roll-forming and longitudinal welding has been carried out. Machining into finished tubes remains to be done.

In all cases, the basic material used for rolled plate has been continuous cast with a rectangular cross section measuring 835x250 mm. The slabs are cut to adjusted lengths for different plate dimensions. Chemical analyses are determined at the material supplier's facilities in the beginning and at the end of each charge. One charge is sufficient for a number of plates, so variations in analysis between different plates differ only to a small extent. The material supplier's certificate must, in accordance with KTS 001, be approved by SKB before rolling into plate may be done. The material for the T 6 – T 15 tubes accorded completely with the valid specification.

After rolling to plate in the respective dimension, test samples were extracted to determine grain size and for static tensile test bars to determine mechanical properties. Table 4-3 shows obtained results.

Table 4-3. Material data for rolled plate for T 6 – T 15 tubes

Tube no.	Plate thick-ness (mm)	Ultimate tensile strength R_m (N/mm^2)	Yield strength $R_{p\,0,2}$ (N/mm^2)	Elonga-tion $A_{50\,mm}$ (%)	Hard-ness (HRF)	Grain size (μm)
T 6	65	212–215	174	78	71–72	400
T 7	40	221–232	203–228	74–80	75–83	250–600
T 8 – T 11	60	213–236	156–201	80–84	73–83	250–600
T 12 – T 15	60	217–229	190–219	80–98	75–82	250–350

Obtained grain sizes varied to a relatively large degree and, in some of the plates, definitely exceeded the specified 180–360 μm. On the other hand, grain sizes in the last delivery of plates for tubes T 12 – T 16 lay within the specified interval. Before delivery, all plates were ultrasound inspected to discover interior faults. No indications were registered.

After roll-forming and machining of surplus measurements and fusion faces, the tube halves were sent to TWI for longitudinal welding. See figures 3-3 to 3-5. The welding of all tubes has been done in the TWI high vacuum chamber, figure 3-5. Since the EB welding of copper tubes is still in a development phase, different variations of fronting bar, backing bar, V-formed welding seams and such, were tested. During the actual welding, occurring phenomena that may effect the quality of the welding were continuously registered, such as electron gun flashovers.

After the welding had been carried out, the tubes were sent to another company for machining and follow-up inspections of the welds by means of penetrants and x-ray.

The results of this testing are still being evaluated. The occurrence of both porosities and surface defects in welding seams has been established. Acceptance criteria for non-destructive testing of welding seams on the copper canister have not yet been produced but are being developed. Therefore, it is not possible to directly assess the results of these test welds against acceptance criteria at this stage. However, it is possible to establish that the welding technique was gradually improved during the testing series, and that the last welds have proved to be of much better quality than earlier welds. It can also be established that the welding of the thinner T 7 tube has been "easier" to carry out and yielded better results than the tubes with thicker walls. In addition, the assessment of TWI is that reduced pressure welding, which is the technique intended for future use in the welding of copper canisters, will result in the welds obtaining a better quality.

When fully developed, the methods of roll-forming of tube halves and longitudinal welding will probably provide a functional manufacturing method for the copper tubes in SKB canisters.

4.2.2 Seamless tube manufacturing, pierce and draw processing

Three ingots were manufactured one after the other through continuous casting for the first tests done by pierce and draw processing. The ingots were butt trimmed at both ends, but the outer surfaces were kept unmachined. The data for the three ingots is presented in table 4-4 below. Continuous casting yields relatively small variations in chemical analysis. The phosphorus content for the three ingots is somewhat higher compared to the specified interval of 40–60 ppm. An oxygen content of 60 ppm deviates markedly from other values. The requirement for oxygen content was, at the time, O < 6 ppm instead of O < 5 ppm, which is the current requirement as outlined in KTS 001, appendix 9.

Table 4-4. Material data for the manufacturing of copper ingots by pierce and draw processing

Tube no.	Length (mm)	Copper ingot – basic material				Current manufacturing situation
		Diameter (mm)	Weight (kg)	Analys		
				P (*) (ppm)	O (*) (ppm)	
T 16	2201	860	11470	79/ 85	4.2/ 60	Pierce and draw processed – see results below
T 17	2243	855	11610	60/ 70	1.8/ 2.4	Pre-formed by upset forging
T 18	2230	857	11550	40/ 70	2.9/ 10	As ingot

(*) Test from the upper end and bottom of the ingot

The manufacturing of tube T 16 was the first time a copper tube of this dimension was manufactured in this way. The required final measurements were to allow for necessary work margins in accordance with the 00001-111/00 drawing in appendix 1. Comparison figures were supplied through measurements of the tube material "before machining", included in the same drawing. Because of the uncertainty of the outcome, the supplier wanted to use a working temperature in excess of the needed temperature to ensure that the forming could be carried out with the available press power. The first stage in the manufacturing was the pre-forming through upset forging to a cylinder with a diameter of 1040 mm. The actual manufacturing of the tube was then done in several stages. First, the punching was done with maintained bottom at 800 °C to approximately Di 690 mm and approximately Do 1050 mm. The tube was then expanded and drawn out length-wise in several steps with successive changes of mandrels and outer rings, and with re-heating of the material in between. During the first stages, the temperature was 850 °C. The second last step was executed with a 905-mm diameter mandrel and a ring with an inner diameter of 1090 mm at a temperature of 800 °C. In the final step, a 955-mm diameter mandrel and a ring with an inner diameter of 1100 mm was used, at a temperature of 750 °C. The surplus measurements (compared to the drawing) were estimated on the assumption that the tube would have shrunk to the required measurements after cooling.

The result of this test manufacturing was that the tube had not acquired the full length and that the thickness of the walls varied to a large extent. The following variations were established:

Tube T 16		**Comparison figures**
The length of the tube after butt trimming of the ends:	4500 mm	> 4900 mm
Inner diameter:	932–952 mm	940 mm
Outer diameter:	1084–1098 mm	1060 mm
Thickness of the walls:	57–90 mm	60 mm

The result of this trial test was that the tube was somewhat shorter than required and had an unnecessary surplus of material in the walls to be machined off. Also, the very uneven thickness of the walls is not desirable from a machining point of view.

When the ends were butt trimmed, a ring was obtained from the open top end of the tube, together with a "plate" from the bottom end. In addition, two cuts were also made in the middle of the tube length, and a ring-formed sample was thus obtained. These samples were metallographically examined with cuts both length-wise and across the tube in order to study the obtained grain size.

Average grain size:

Tube T 16	**Length-wise cut**	**Cross-cut**
The bottom	1060 µm	1100 µm
The middle	365 µm	370 µm
The top	470 µm	350 µm

The requirement for average grain size in accordance with KTS 001, appendix 9, is 180–360 µm.

The coarsest grain size was found in the bottom part. It holds a relatively heavy concentration of material, which also takes longer time to cool after the forming. That the largest grain size is found here is only natural. However, the test must be regarded as promising. In future new tests, the tubes must be considerably more elongated while, at the same time, the final stage can probably be carried out at a lower temperature. Combined, this should result in improvements in both measurements and obtained structure of material.

The planned continuing tests will prove whether or not pierce and draw processing can be an alternative in the manufacturing of seamless copper tubes.

4.2.3 Seamless tube manufacturing, extrusion

Copper tubes with the identification numbers T 3 and T 4 that were manufactured by means of extrusion, have been accounted for in reference [2]. T 3 is one of the components in the exhibition canister designated C 2. These tubes were both extruded at 800 °C, a temperature that proved to be too high, causing a too coarse grain structure in the material.

For the now completed test series, three ingots were manufactured one after the other through continuous casting. The ingots were butt-trimmed at both ends and the outer surfaces were turn-cleaned. This contributed to better quality surfaces on the extruded tubes. Data for the three ingots is presented in table 4-5 below. As in the case of the ingots used for pierce and draw processing, the obtained phosphorus content is higher than the specified 40–60 ppm. However, the oxygen content requirement of O < 6 ppm was met.

Table 4-5. Material data regarding the manufacturing of copper tubes by extrusion.

		Copper ingot – basic material				
Tube no.	Length (mm)	Diameter (mm)	Weight (kg)	Analysis P (*) (ppm)	Analysis O (*) (ppm)	Current manufacturing situation
T 19	2299	838	11350	74/ 85	2.3/ 5.2	Extruded – Non-machined
T 20	2273	840	11275	58/ 79	2.4/ 5.2	”
T 21	2290	840	11361	55/ 70	2/ 3.1	”

(*) Test from the upper end and bottom of the ingot

The first stage in the process, the pre-forming and punching into blanks for extrusion, was done at a temperature of 675 °C with all three ingots at the same time. The extrusion was also performed at 675 °C for all three tubes. T 21 was extruded first, and then evaluated with regard to measurements and structure of the material. An ultrasound inspection was also carried out. The other two tubes were then extruded one after the other, followed by the same inspection process as for the first tube.

As in the case of pierce and draw processing, the required final measurements were to allow for necessary work margins in order to assemble a tube in accordance with drawing 00001-111/00 in appendix 1. The comparison figures as specified in the drawing were estimated “before machining”. Obtained measurements are shown in table 4-6.

Table 4-6. Measuring of extruded copper tubes.

Tube no.	Length Comparison figure > 4900 mm	Inner diameter Comparison figure 940 mm	Outer diameter Comparison figure 1060 mm	Thickness of walls Comparison figure 60 mm
T 19	5013	941 – 962	1072 – 1073	65.0 – 67.0
T 20	5006	938 – 945	1072 – 1073	64.5 – 68.4
T 21	5010	936 – 944	1067	64.5 – 67.0

Deviation in measurement has been established. The inner diameter of the ready-machined tube is 952 +1/+0.5 mm, according to the drawing. The 962 mm local value of the inner diameter for T 19, means that a certain section of the tube will not be accessible for machine-cleaning on the inside. All other measurements are approved with relatively small variations that should not cause any problems during the final machining.

All three tubes were examined with ultrasound. No defects were established. Figure 3-13 is a photo of the three extruded tubes.

Samples taken from the end-area of all three tubes were metallographically examined in order to determine grain size. In the T 21 tube, samples from both the top and bottom of the tubes were studied. From the other two, samples were taken from the bottoms. The top of the tube is the part that first comes out from the tool during extrusion. The following results were obtained during the determining of grain size, table 4-7.

Table 4-7. Results of the determining of grain size on extruded tubes.

Tube no.	Grain size	
	Top	Bottom
T 19		44 – 88 μm (ASTM 6 – 4)
T 20		44 – 88 μm (ASTM 6 – 4)
T 21	88 – 177 μm (ASTM 4 – 2)	52 – 88 μm (ASTM 5.5 – 4)

The requirement for average grain size as specified in KTS 001, is 180–360 μm. A smaller grain size than 180 μm ought not prove to be a disadvantage. The result will be followed up with new material tests and another extrusion test. Figure 4-1 is a photo of the structure in the top section of the T 21 tube.

***Figure 4-1.** The structure in the top section of the T 21 tube. 100x.*

To summarise, it has been established that the extrusion testing has obtained satisfactory results. Extrusion is in all probability a good alternative for future production of seamless tubes for SKB´s copper canisters.

4.3 Manufacturing of lids and bottoms in copper

Lids and bottoms in copper are manufactured from pre-formed forged material. Forged material can be used for the manufacturing of both lids and bottoms. The current drawings can be found in appendix 1. The number of the drawing depicting the lid, is 00001-31/00, and the number of the drawing depicting the bottom, is 00001-112/00. In all, 42 forged blanks have been produced up until now. The rather large number is due to the Canister Laboratory's need for copper lids.

The basic material for forging is continuous cast material. One length of ingot is enough for four forged blanks. The continuous casting results in very small variations in the chemical composition. The material requirements for lids and bottoms are the same as for copper tubes, i.e. in accordance with specification KTS 001 in appendix 9.

The analysis certificates for these 42 blanks show that the requirements specified in KTS 001 are met in regard to oxygen, hydrogen and sulphur. The phosphorus content varies within the 34–80 ppm interval, while the requirement specify 40–60 ppm.

One inspection of grain size in a forged blank has hitherto been carried out. The grain size was established at 200–300 μm close to the centre of the material, which is the area in which the coarsest grain size can be expected to occur. Therefore, the requirement of 180–360 μm seems to be met when applying this manufacturing method.

4.4 The welding of bottoms on copper tubes

On two of the manufactured copper tubes, the bottom has been applied by means of EB welding at TWI. This welding too, was done in the TWI high vacuum chamber. The tubes were placed horizontally on a customised rig that rotated the tube during the welding process. Figures 4-2 and 4-3 show the fitting of the bottom onto tube T 9 and how the tube is placed in the vacuum chamber for welding.

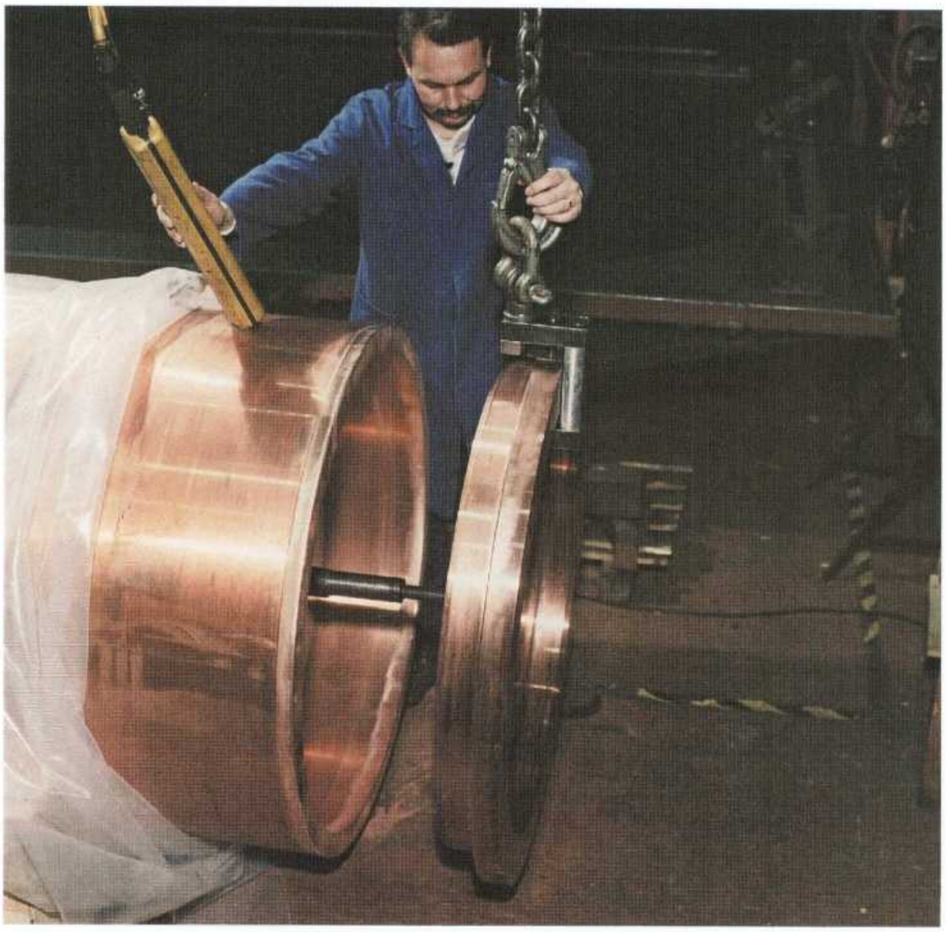

Figure 4-2. *The fitting of the bottom onto tube T 9.*

Figure 4-3. *Tube T 9 in the vacuum chamber for the welding on of the bottom. The picture also shows the location of the electron gun. During the welding, the tube is rotated while the electron gun remains in a fixed position.*

Bottoms were welded onto two of the manufactured tubes, no. T 9 and T 10. The bottom designated by the identification number TB 3 was welded onto T 9, and TB 4 onto T 10. Occasional flashovers were noted during both welding procedures, and in one instance a local welding reparation was carried out.

After the welding, the quality of the welds were inspected with ultrasound (P-scan), see figure 4-4. No indications of welding defects were registered, apart from certain weld defects at the root originating from the termination of the full turn upon completion of the welding. Figure 4-5 is a photo of a part of the welding string at the bottom of tube T 9.

The T 9 and T 10 tubes will be part of fully assembled canisters to be used in different tests. Regarding T 9, see figures 4-11 and 4-12 below.

Figure 4-4. *Ultrasound examination (P-scanning) of the bottom weld on TB 3/T 9.*

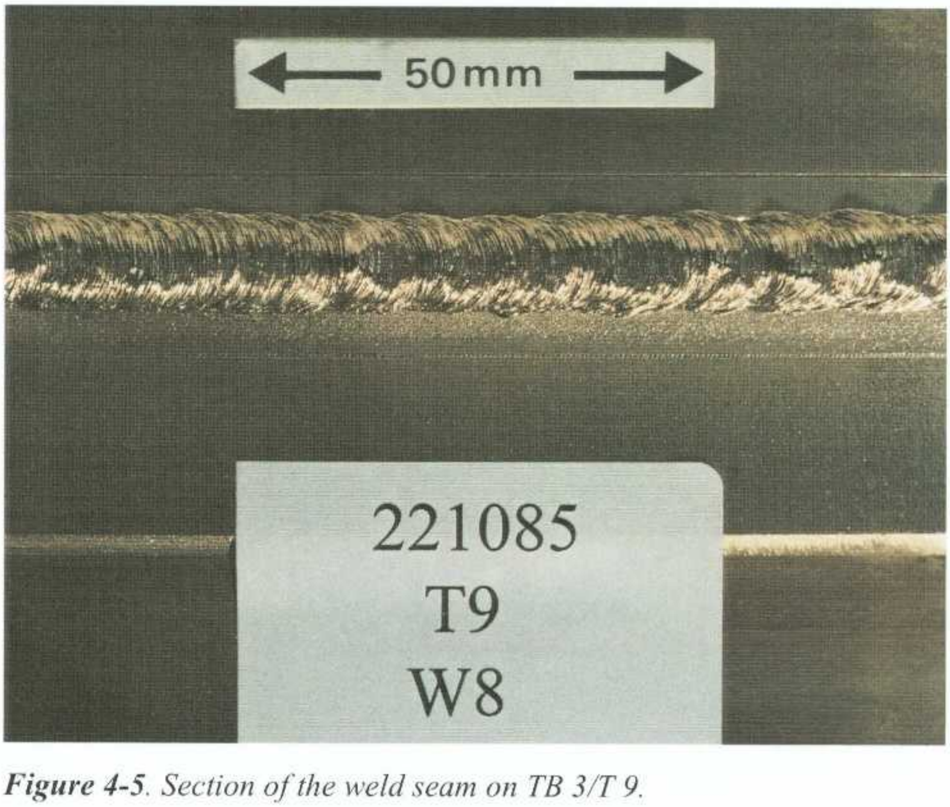

Figure 4-5*. Section of the weld seam on TB 3/T 9.*

4.5 Manufacturing of cast inserts

4.5.1 Overview

As shown in table 4-1, 8 inserts were manufactured in nodular iron and 1 in cast steel between 1996 and 1998. During an earlier test, half a length in cast steel was also manufactured, see below. One of the nodular iron inserts is designed for PWR fuel assemblies, the others are for BWR fuel assemblies.

Regarding identification numbers on the inserts, I 1 – I 4 belong to the earlier tests as reported in reference [2]. These inserts were designed differently and were not manufactured by casting.

In the current test series, I 5 and I 6 have been manufactured in cast steel and I 7 – I 13 in nodular iron. All of these inserts have been designed for BWR fuel assemblies with 12 channels. Added to this lot is the nodular iron insert for PWR fuel assemblies that also has been manufactured.

4.5.2 Cast steel inserts

Two test castings of inserts in steel have been carried out. During the first test cast, a half-length insert was manufactured. (I 5, upper section.) At the time, the current design was based on the finished insert consisting of two halves to be assembled, see drawing SKB-20001-3D/00 and SKB-20001-12/00 in appendix 2.

During the second cast, which built on experiences gained from the first, a full-length insert (I 6) was manufactured in accordance with drawing SKB-20002-121/00. The insert was equipped with a welded bottom (drawing SKB-20001-123/00) and was machine-finished in accordance with SKB-20002-12/00 in appendix 2.

In both cases, the channels for fuel assemblies were made by welding together steel profiles (RHS 180x180x10 mm) to a cassette that was centrally placed in the casting mould and then cast into the material in accordance with the principles shown in figures 3-13 and 3-14.

The cast steel used was SS 141306-02. After casting and fettling, but before machining, double heat treatment was carried out. I 5 was heat treated at 1000 °C followed by normalisation from 920 °C, and I 6 was double-normalised, first from 925 °C, and then from 920 °C. In table 4-8, the chemical analysis from delivery certificates have been summarised and compared to standard requirements, and in table 4-9 the same comparison is made for data concerning tensile strength. Tensile strength values have been assessed from cast-on tensile test bars.

Table 4-8. Chemical analysis in accordance with certificates for inserts in cast steel. I 5 and I 6.

	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Cu (%)
SS 1306 (Requirements)	Max 0.18	Max 0.60	Max 1.1	Max 0.035	Max 0.030	Max 0.3	Max 0.3
I 5	0.16	0.56	0.90	0.007	0.008	0.26	0.064
I 6	0.18	0.60	1.04	0.012	0.014	0.22	0.050

Table 4-9. Tensile strength values for inserts I 5 and I 6 in steel casting. Cast-on tensile test bars 14.0 mm.

	Yield strength R_{eL} (N/mm^2)	Ultimate tensile strength R_m (N/mm^2)	Elongation A_5 (%)	Contraction Z (%)	Impact strength Kv 0°C (J)	Hardness (HB)
SS 1306-02 (Requirements)	Min 220	Min 400	Min 25	Min 45	Min 27	–
I 5	260	430	30	61	48, 60, 81	135
I 6	317	470	31	66	87, 93, 90	130

Testing was also done with penetrants and ultrasound. The casting of I 5 is to be considered as a trial test with very uncertain results. I 5 also showed extensive occurrences of porosities and transverse cracks between the channels. The cast-in steel profiles were also in part heavily deformed due to pressure and the temperature from the liquid metal during casting. After this casting, the cast system was modified, among other things, with the aim of improving results. The results of I 6 did turn out to be improved, but porosities and transverse cracks between the fuel assembly channels could also be established in the insert. Inner porosities were mainly located in the thickest parts of material in the insert, see figure 4-6. Defects in both the cylinder surface and the two butt surfaces were repaired by welding, and the separate steel bottom was welded onto the insert before the machine-finish was carried out. (The cast steel chosen has good welding qualities.) The deformation of the fuel assembly channels was considerably less compared with I 5, and a 154x154 mm square profile template with a length of 2300 mm, could be freely moved down to the bottom in all channels. See paragraph 4.2 in KTS 011, appendix 10.

In both I 5 and I 6, no significant metallic bonding had occurred between the steel profiles and the steel casting.

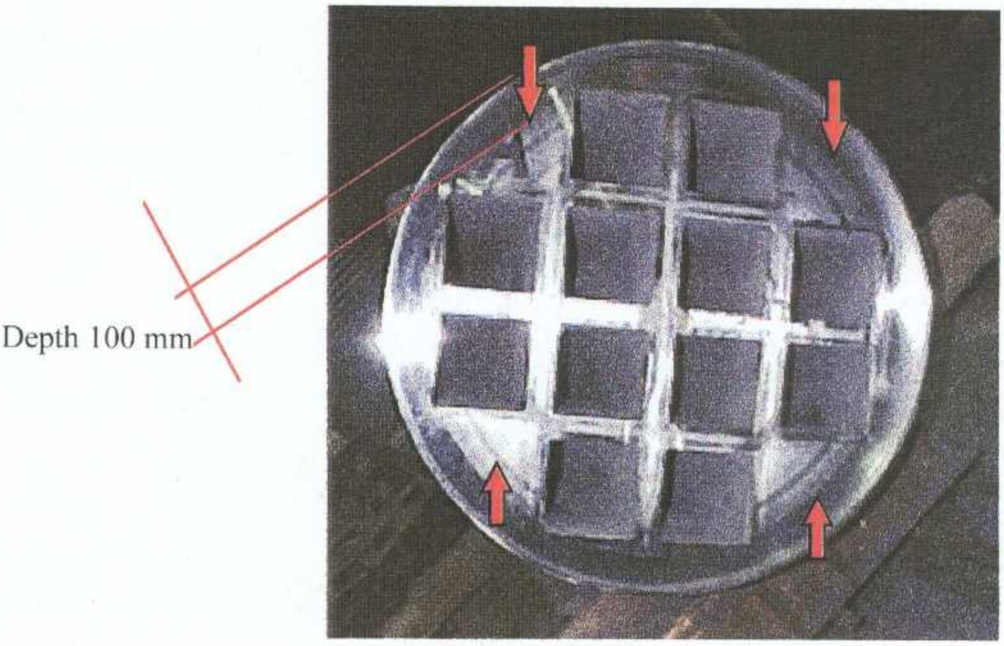

Figure 4-6. *Results of ultrasound testing of insert I 6. Indications appeared along the length of the insert in the four material concentrations marked with arrows. The sizes of the defects were max 6 mm and specially concentrated to a depth of approximately 100 mm under the surface.*

4.5.3 Nodular iron inserts

7 inserts for BWR fuel assemblies and 1 insert for PWR fuel assemblies have been cast in nodular iron. The casting has been performed at three different foundries. Nodular iron casting differs from steel casting in that the inserts can be directly cast with integrated bottoms. Inserts I 7 – I 10 and insert I 12 have to all extents been manufactured in this way and in accordance with drawings 00004-12/00 and 00002-1211/00 in appendix 1. (Minor adjustments have been made during the course of work.)

The nodular iron used meets with Swedish standard SS 140717-00. The current specification applicable for cast inserts in nodular iron, is KTS 001, which is outlined in appendix 10. Contrary to the steel casting procedure, no heat treatment is needed after casting. The casting is knocked out after cooling in the mould and can then be machined.

Obtained material data, consisting of chemical analysis and tensile strength values from delivery certificates and testing conducted by own hand, has been summarised in tables 4-10, 4-11 and 4-12.

Table 4-10. Chemical analysis according to certificates for nodular iron inserts.

	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Ni (%)	Mg (%)	Cu (%)
SS 0717:	3.2–4.0	1.5–2.8	0.05–1.0	Max 0.02	Max 0.08	0–2.0	0.02–0.08	–
I 7	3.53	2.34	0.33	0.015	0.011	0.05	0.047	0.25
I 8	3.76	1.97	0.295	0.015	0.006	–	0.039	0.057
I 9	3.74	2.35	0.33	0.017	0.009	0.06	0.043	0.145
I 10	3.52	2.28	0.31	0.010	0.010	0.04	0.050	0.27
I 11	3.54	2.46	0.32	0.015	0.010	0.04	0.043	0.26
I 12	3.73	1.96	0.227	0.013	0.009	–	0.040	0.040
I 13	3.71	2.41	0.36	0.013	0.01	0.05	0.043	0.157
PWR no. 1	3.60	2.54	0.33	0.019	0.012	0.03	0.051	0.21

Table 4-11. Tensile strength values for nodular iron inserts. Cast-on tensile test bars.

	Yield strength $R_{p0,2}$ (N/mm^2)	Ultimate tensile strength R_m (N/mm^2)	Elongation A_5 (%)	Hardness (HB)
SS 0717-00	(250–320)	(400–520)	(26–15)	135–180
I 7	274	450	20	149
I 8	230	370	22	121
I 9	282	390	20	139
I 10	290	426	22	149
I 11	305	420	21	150
I 12	225	364	23	123
I 13	263	372	13	132
PWR no. 1	280	420	22	150

One of these inserts, I 7, has been examined in more detail. In connection to the casting, thermocouples were attached to the bottom, middle and top sections of the insert surface. Figure 4-7 shows the three cooling curves. The temperature of the melt in the initial phase of the casting was 1350 °C.

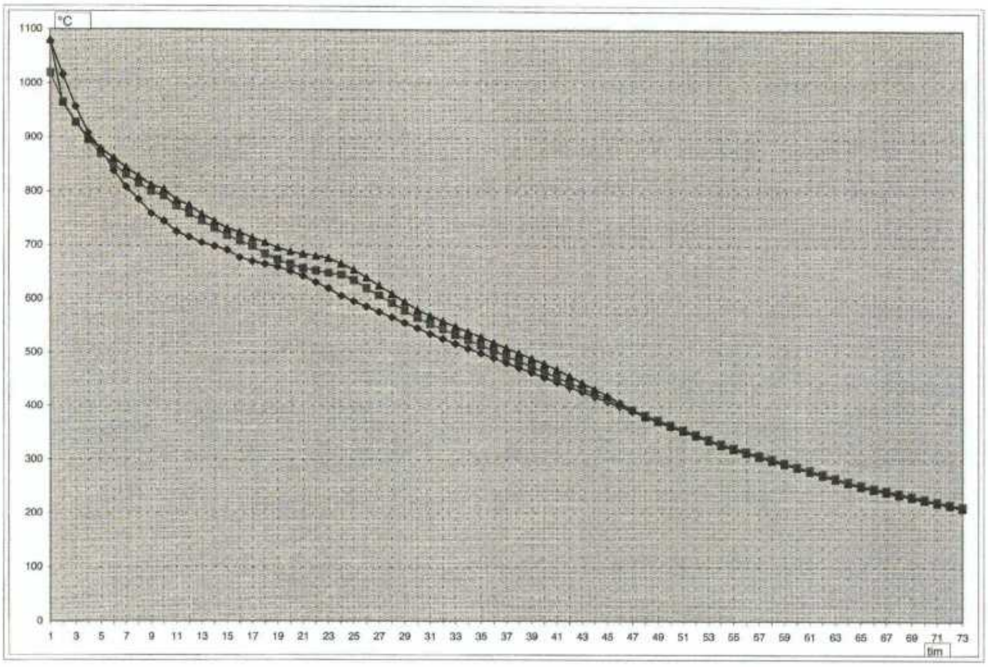

Figure 4-7. *Cooling curves for insert I 7. The thermocouples were attached, in the casting mould, to the surface of the casting at the bottom, middle and top sections of the insert. The casting temperature was 1350 °C.*

The structure was studied in a tensile testing bar cast in the same test, figure 4-8. The structure is mainly ferritic with pearlite elements occurring (97% ferrite). The graphite has been classified as VI 6 in accordance with ISO 945–1975. This meets the standard requirements.

Figure 4-8. *The structure in a tensile testing bar for insert I 7, cast in the same test. Etched 2% Nital. (100x)*

I 7 was also cut into smaller pieces in order to, among other things, conduct material testing of the material in the actual insert. Test bars for tensile testing and compression testing were extracted from the thickest pieces of material, from both the bottom of the insert and at about middle height. Table 4-12 shows the results of these tests.

Tensile testing was carried out in accordance with SS-EN 10002, and the compression testing in accordance with ASTM E9-89A.

Table 4-12. Results of tensile testing and compression testing of insert I 7.

	Tensile testing			**Compression testing**
	Yield strength $R_{p0,2}$ (N/mm²)	**Ultimate tensile strength R_m (N/mm²)**	**Elongation A_5 (%)**	**Yield strength $R_{c\,0,2}$ (N/mm²)**
Test bars from the bottom section of the insert	289	419	–	304
	291	447	8	302
	291	437	8	303
Test bars from the middle height of the insert	274	415	9	305
	274	414	10	302
	273	401	8	302

It can be established that the values for yield strength and ultimate tensile strength correspond well to comparison values in table 4-11 from the test bars cast in the same test. The elongation values in table 4-12 are, however, considerably lower. This may be due to a coarser crystal structure in the thicker sections of the actual insert. This will be further investigated.

Figure 4-9 is a photo depicting the cylindrical test bars used in the compression testing.

As with the steel casting, it has been established that there is no continuous metallic bonding between steel profile walls and the nodular iron.

The cast inserts have been examined by means of ultrasound and penetrants. As was stated above, the casting has been done at three different foundries. To all purposes, the nodular iron has been proved to be homogeneous and without significant defects. In some of the first tests, minor breakthroughs of metal liquid through profile walls, or steel profiles coming loose and moving during casting, have occurred. This may result in unhomogeneities in the material, which will also be detected during ultrasound testing. However, it has been established that these problems can be solved by means of casting technology measures.

A further development of the requirement specification in accordance with KTS 011 in appendix 10, will be included in the continued work.

In short, after having carried out these tests, it can be established that casting in nodular iron is, in all probability, a good method for the manufacturing of inserts for canisters.

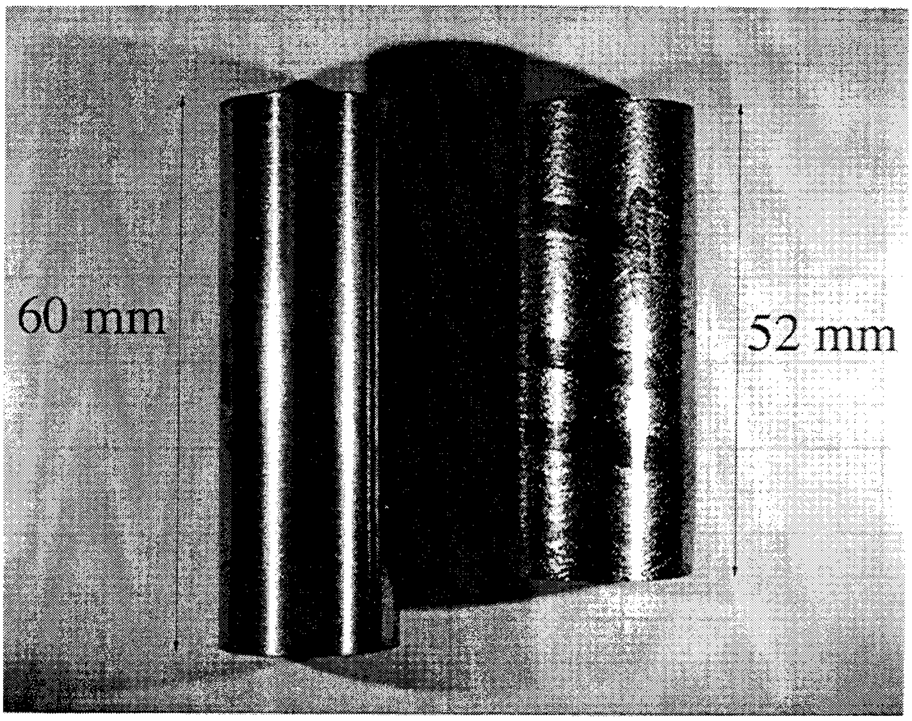

Figure 4-9. *Cylindrical test bars from insert I 7 before and after compression testing.*

4.5.4 Comparison between nodular iron and cast steel in inserts

As described, test casting of inserts in both nodular iron and steel has been carried out. The conducted tests have proven that for this particular use, nodular iron has more advantages compared to steel casting. Nodular iron has better casting properties, which, among other things, enables the inserts to be cast with integrated bottom. If steel casting is used, a separate bottom must be manufactured and welded onto the insert.

Another property that, at least for this use, is a disadvantage of steel casting, is the significantly larger shrinkage on solidification. This increases the disposition for the occurrence of porosities in the material and, in our particular case, probably also the risks of transverse cracks emerging.

Steel casting inserts must be heat-treated before machining to obtain the required structure and machinability in the material. This is a more expensive process.

The conclusion is that, at present, nodular iron is the sole material of which inserts will be made.

4.5.5 Design development of the BWR inserts and design of the PWR inserts

An improvement in the design of the BWR inserts, mainly of a casting technical nature, has been made. In order to achieve a more even distribution of material in the cast iron, test casts have been carried out with a modified cassette in accordance with drawing 00002-1211-1/B in appendix 3. In this version, special "cooling tubes" in round dimensions have been placed in the four material concentrations referred to in figure 4-6. The purpose was to obtain a more even solidification and cooling process with smaller risks of cast defects occurring. Inserts numbered I 11 and I 13 in section 4.5.3 above have been cast using this design solution. There are additional advantages to using cooling tubes, namely, that they can be used in the assembling of hoisting equipment needed to place the inserts in the copper tubes.

One PWR designed insert, referred to in section 4.5.3, has been cast. In appendix 4, 5 drawings are included showing the design in question. The drawing for the machine-finished insert is numbered 00005-12/B, and the drawing for the steel profile cassette is numbered 00005-1211/C. As can be seen in the drawings, extra "cooling tubes", in this case with rectangular profiles, have also been included in the design for the same purpose as discussed above. Figure 4-10 is a photo of insert I 11 and this first PWR insert.

Figure 4-10. *Cast inserts of nodular iron in accordance with the developed design with extra "cooling tubes" for a more even distribution of material. Insert I 11 is to the left in the picture, and the first PWR insert manufactured, is to the right.*

4.5.6 Assembling complete canisters

During 1998 and 1999, 8–9 complete canisters will be assembled and used in different projects at the Äspö Hard Rock Laboratory. A number of these canisters will be equipped with internal electrical heaters in order to simulate the residual heat that spent nuclear fuel emits. A first canister, C 3, has been assembled at Kockums Industrier AB in Malmö in order to test heat elements and the control equipment. See figures 4-11 and 4-12. During the testing, temperature measurements will be carried out on a number of different locations inside the canister, as well as on the canister's outer surface, using various effect levels in the heat elements.

Figure 4-11. *The assembling of a complete canister, C 3. The insert (I 10) is lowered into the copper casing, (T 9 and TB 3).*

Figure 4-12. *Heat elements with the same measurements as the BWR fuel assemblies, are placed in the channels of the insert. The canister is equipped with a number of thermal elements both internally and externally.*

5 Studies of alternative manufacturing techniques and development of technology

5.1 Alternative methods for the manufacturing of copper tubes, hot isostatic pressing, spray forming and electro-deposition

5.1.1 Hot Isostatic Pressing, HIP

Hot Isostatic Pressing means that the material, which usually consists of powder but can also consist of homogeneous components, is subjected to an outer pressure. By increasing the temperature, a deformation and diffusion process takes place between the metal surfaces being pressed against each other. This results in the joining of the metal surfaces and, at the correct choice of parameters for pressure, temperature and time, a complete joining whereby a compact and homogeneous material is formed.

Hot Istostatic Pressure of powder for the manufacturing of SKB copper canisters, has been studied since the beginning of the 1980s. In RD&D 95, reference [1], there is a description of these activities with a number of further references. It can be established that a considerable problem is that of gaining access to good quality copper powder. The copper powder offered in the market, consists of particles that have oxides on the surface. The problems of pollution have meant that no new HIP tests with copper powder have been carried out, and continued work will not be undertaken in view of the present difficulties.

An alternative that has been suggested in order to avoid the copper powder problems, is to use sheet metal as a basic material instead. A thick-walled component built of relatively thin copper sheets should, after being subjected to HIP, obtain good enough material properties if the sheets can be thoroughly cleaned from surface oxides and other pollutants before an HIP process is undertaken.

A number of laboratory tests based on this idea have been carried out. Figure 5-1 shows a model of a copper canister with a height of 180 mm, an experiment in which copper sheets were hot isostatically pressed against a steel insert. The bottom consists of ten layers of 2 mm thick copper sheets, and the walls consist of eight layers.

***Figure 5-1.** The picture shows how copper plating has been densified by hot isostatic pressing, and how the copper material joins to the steel insert. The bottom consists of ten layers 2 mm thick sheets, and the walls of eight layers.*

In all, the tests have proved yet again that pollutants, in this case on the surface of the sheets, are a major problem. Tests involving different cleaning methods, both mechanical cleaning and chemical cleaning have been undertaken. Good metallic bonding is partially obtained, but it has not been possible to obtain acceptable total homogeneity in the material.

Tests involving this technique have been concluded and will not be continued at present.

5.1.2 Spray forming

Spray forming is a powder metallurgical method by which liquid metal is directly transferred to a solid body. Using nitrogen, the liquid is dissolved into small droplets that are quickly solidified by the cooling effect of the nitrogen. The solidified droplets are joined together to a solid body with high density. At present, the method is used industrially by Osprey Metals

Ltd for the manufacturing of tool steel, high-speed steel, stainless steel, nickel-base alloys and titanium-aluminium and copper alloys. The principle for the manufacturing of tubes using this method, is demonstrated in figure 5-2.

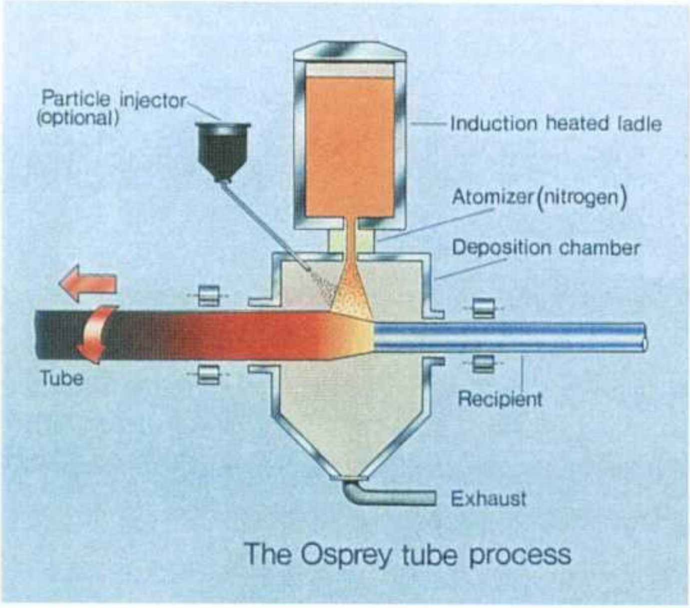

Figure 5-2. *Manufacturing of tubes using the Osprey process.*

The possibilities of manufacturing copper canisters with spray forming have been studied. The studies showed that pure copper without pores could probably not be manufactured. The copper alloy currently used in the SKB copper canisters, does not have an alloying element that chemically can bond nitrogen. This means that the nitrogen gas used in the process may become incorporated in the metal and result in pores being created. A way of avoiding this could be to alloy the copper with zircon, which is a powerful binder of nitrogen.

Due to these difficulties, SKB has decided not to continue work on spray forming at present.

5.1.3 Electro-deposition

Electro-chemical deposition or electrolysis is a well-known technique for transporting copper in a liquid. The method is of major use in the production process of copper, in which it is used in the manufacturing of copper cathode plates. It is a purifying process in which crude copper, after having been cast into plates, is electrolysis-refined and forms pure copper in the form of cathode plates.

This technique for the manufacturing of SKB copper canisters, was originally suggested by Boliden Mineral AB. The technique entails that the insert be directly coated with copper through electrolysis. Figure 5-3 is a schematic drawing of how the process could work.

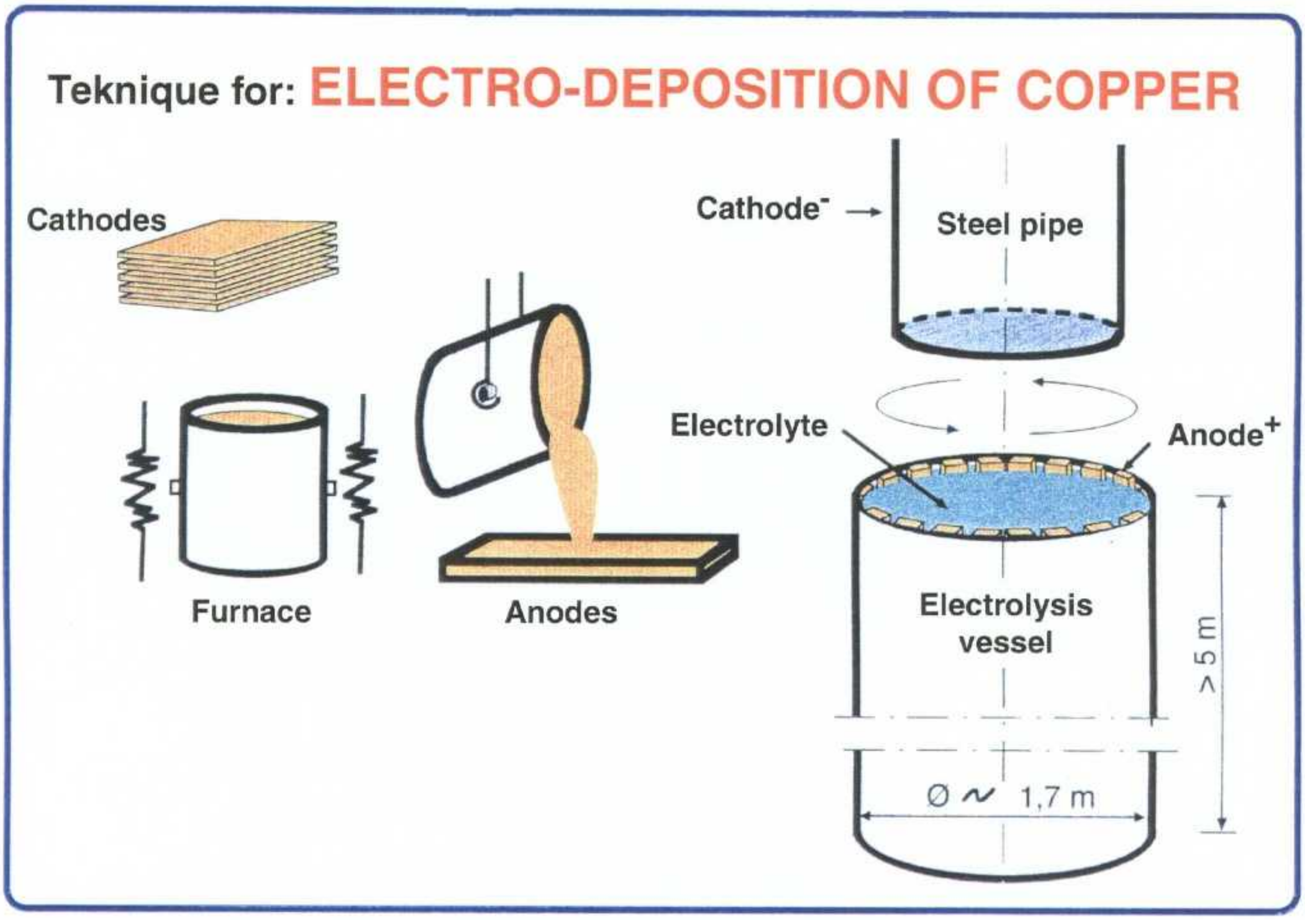

Figure 5-3. Electro-deposition of copper

In short, the method entails that copper of good quality is melted and cast into bar-shaped anodes. These bars are then assembled on the inside of the electrolysis vessel that will constitute the cell for the electrolysis process. The insert is attached as cathode and the electrolysis vessel with copper staffs as anode. The electrolyte is primarily composed of copper sulphate and sulphuric acid. Parameters for intensity of current, the electrolyte, inhibitors, temperature and so on, are chosen, and the process is allowed to progress until a sufficiently thick layer of copper has been formed on the insert. Deposition of this kind can be time-consuming and progress during several days. The deposition speed has been assessed at 1–2 mm/ 24 hours.

Electrolysis-coated copper has an extremely fine-grained structure. This can be modified through heat treatment if so needed.

A study of the technique has been undertaken by the Luleå University of Technology on behalf of SKB. In connection with this, an electrolysis cell was constructed in the laboratory for preliminary tests. The purpose has been to conduct preliminary studies of effects from different process parameters. The aim has also been to produce material in order to carry out metallographic examinations and testing of mechanical properties of copper manufactured in this way.

A number of experimental conditions have been implemented and copper sheets have been manufactured for evaluation. At present, the results are being put together and an evaluation will be carried out. Today, it is uncertain whether or not SKB will continue working with this technique.

5.2 The development of steel lids for inserts

One of the stages in the future encapsulation process, after having lowered the fuel assemblies into the canister insert, is to pump out the remaining air and substitute it with argon. This will be managed through a valve in the steel lid covering the insert. During the later stage of EB welding of the copper lid, the insert will have an inner overpressure compared with the air pressure in the welding chamber. Because of this, the insert lid must be sealed tight. The current design of lids for inserts can be seen in the drawings 00003-21/00 and 00003-211/00. The steel lid is placed on the insert and screwed on with a centre bolt. The lid is sealed tight with the help of O-rings placed against the surface of the insert.

A tightness test of the insert lid must be possible to do after the atmospheric change. Pressure testing with different kinds of lid design and O-rings has been carried out. The drawing TEST-00005-3/A shows an alternative lid design. In this case, the lid has been designed to fit into a conical mounting in the insert with O-rings aimed at sealing these conical surfaces tight. This design has worked well in the tests that have been undertaken so far. Continued testing will show whether or not this lid design will replace the earlier design.

5.3 Developing the welding technique friction stir welding

Preliminary studies of an alternative welding technique have been initiated by SKB. As with electron beam welding, the work is done in collaboration with TWI. The principle of Friction Stir Welding (FSW) is shown in figure 5-4. The method has been developed by TWI, which also has taken out patents on the technique.

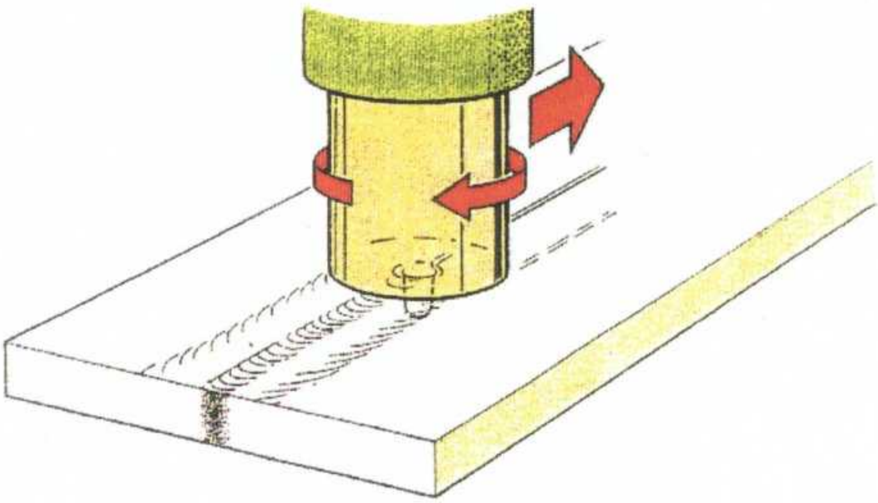

Figure 5-4. *Joining with friction stir welding.*

A specially designed rotating tool is used in friction stir welding. The tool is equipped with a small diameter probe that is pressed down between the fusion faces. When the tool rotates and moves along the joint, heat is generated and forge welding in which the metal parts are joined is achieved. The temperature becomes so high that the metal softens and becomes ductile. In contrast to EB welding, the material does not melt during the joining.

Up until now, the method has primarily been used for joining of aluminium in the aircraft, marine and motor vehicle industries.

SKB and TWI have undertaken preliminary tests with joining copper using this technique. Figure 5-5 shows two copper plates that have been mounted in a water-cooled fixture for joining with FSW technique. So far, test-welding involving various parameters has been made on material up to 40 mm thick. One example of the welding of 40 mm thick plates is shown in figure 5-6. The original joint is located in between the two "curls" in the upper part of the picture. These are formed by the rotating tool's underside during friction against the upper side of the plates, see figure 5-4. The curls will be removed in the subsequent machining. The size of the curls can be effected by the design of the tool. As can be seen in figure 5-6, the structure has, in this case, a relatively even grain size in the whole area affected.

SKB and TWI are currently evaluating the test welds carried out so far and are planning for a continuation of the project.

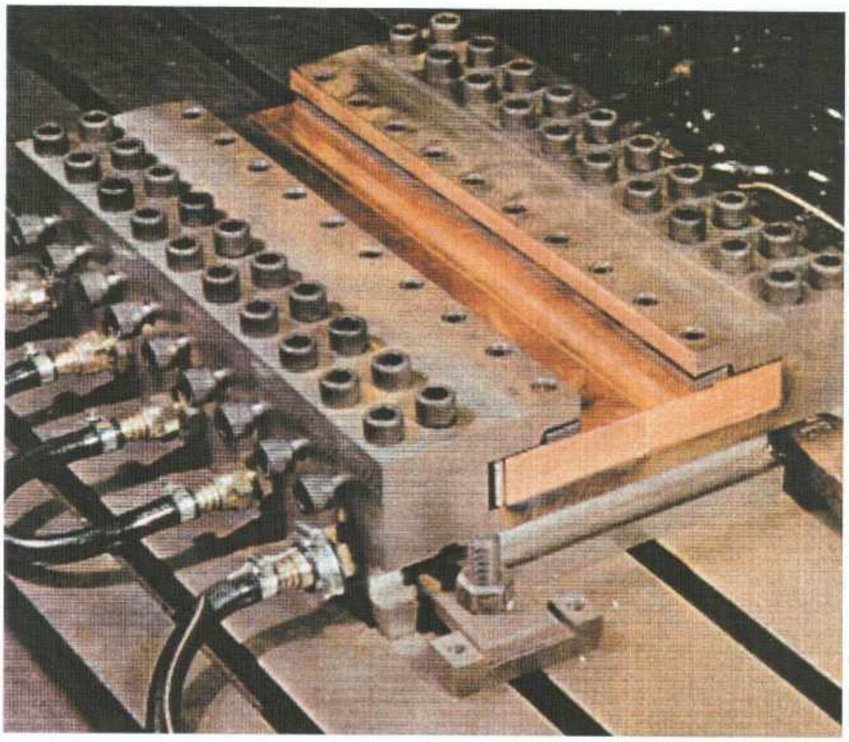

Figure 5-5. *Water-cooled fixture for joining of copper plates with FSW technique.*

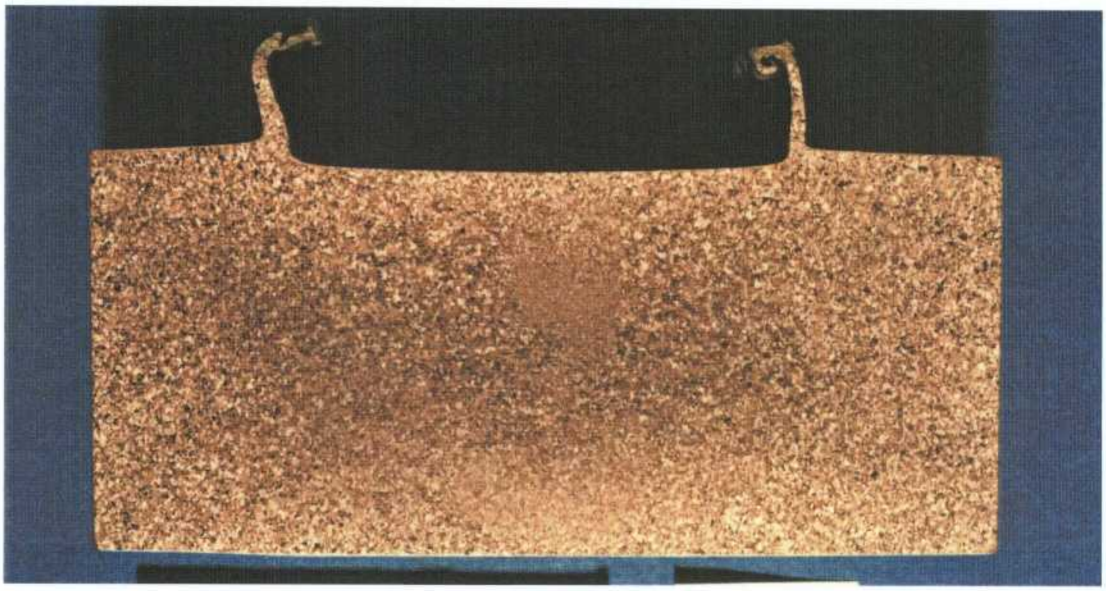

Figure 5-6. *The welding zone in 40 mm thick copper plates after FSW.*

6 The quality assurance system for canister manufacturing

6.1 General

The development of a quality assurance system in accordance with ISO 9001 and IAEA 50-C-QA requirements for canister manufacturing, was initiated during 1997 and is carried out continuously in connection to the test manufacturing. The quality assurance system is adapted to the requirements stated in control documents within SKB, and comprises the whole manufacturing chain from material suppliers up to and including the delivery of assembled canisters.

6.2 The quality assurance manual

The Quality Assurance Manual "Canister Manufacturing" summarises the quality assurance system for manufacturing of canisters. The manual includes references to special procedures and other control documents. The current content of the Quality Assurance Manual can be found in appendix 6.

Procedures that directly or indirectly affect the quality of the canister and canister components are described in the manual. However, activities carried out in connection with the seal-welding of lids onto canisters are not covered in this manual. The manual also places requirements on the quality systems of suppliers mainly delivering components for canisters, and states requirements for SKB to monitor that the requirements placed on these suppliers are met.

The manual also includes a Swedish/English glossary, primarily for the purpose of co-ordinating terminology between the manual and procedures written in English. The manual has been distributed in a limited numbered edition with a specified recipient for each copy.

A separate binder is also part of the quality system, "Drawings, Specifications and Procedures". As can be deduced from the name, the binder consists of current design drawings and the technical specifications that have been referred to above: KTS 001 "Material for Copper Canisters", KTS 011 "Nodular Cast Iron SS 0717 Insert", and KTS 021 "Steel Section Cassette", appendices 9, 10, 11.

Also included in the binder are the current documented procedures. A list of these can be found in appendix 7. The procedures and the technical specifications are written in English so suppliers also outside Sweden can use them.

7 Future production of canisters – the canister factory

Empty canisters will be manufactured in a special canister factory and transported from there to the encapsulation plant. A preliminary study regarding the design of such a plant has already been undertaken, reference [4].

A chart describing the workflow in the planned factory can be found in appendix 12. In this scenario, the copper tubes will be manufactured by roll forming rolled plate to tube halves that will then be welded together with longitudinal electron beam welding, EB welding. After the longitudinal welding, a stress-relief tempering follows, and then inner and outer machining until required measurements have been obtained. Lids and bottoms in copper are machined out of forged blanks. The copper bottoms are then EB welded onto the tubes. All welds are inspected using non-destructive testing with ultrasound and x-ray.

The layout of the plant is designed to enable material in the form of rolled copper plate and forged material for lids and bottoms to be delivered to the factory from external suppliers.

The nodular cast iron inserts are delivered ready-cast and rough-machined to the plant for finish machining. The material for insert lids are manufactured from rolled steel plate and machine-finished at the factory.

After cleaning, the insert is lowered down into the copper tube and the canister is assembled in preparation for final delivery.

A basic principle in the design of the plant is to keep copper and nodular iron apart through all processes from delivery, through machining to assembly.

Figure 7-1. *The canister factory.*

Apart from the flowchart, four pages describing the factory can be found in appendix 12.

With premises for a maintenance shop, offices and a laboratory for inspections, the plant will be approximately 7000 square meters in this design. The total investment costs are estimated to be approximately SEK 300 million. The staff is planned to consist of about 30 people. If the copper tubes are manufactured from seamless tube material instead of rolled plate, the need for machines and floor surface will be affected to a relatively large degree.

A special factory for canister manufacturing has many advantages:

- The machinery equipment, the equipment for non-destructive testing and the laboratory equipment can be customised to suit this particular production.

- If parallel machine-finishing is undertaken in the same building where inserts and copper tubes are being produced, it can be ensured that surfaces are kept clean while awaiting welding and assembling to finished canisters.

- One organic unit in which the whole quality chain from supplier to ready-made product can be overseen, is achieved.

A general study of the copper market has also been carried out, in which supply, manufacturing processes, environmental impacts and prices were looked at, reference [6].

8 Future work

Based on results obtained until now, the work with testing and further developing the manufacturing technique will be continued. The work that has been carried out until now, has proven that SKB has established a concept for canister design and canister manufacturing that, in all probability, can be optimised and tested during coming years to ensure that it can function efficiently in the production process. The current situation and the plans for future work can be summarised as follows:

- For the manufacturing of copper tubes, roll-forming of rolled copper plate to tube halves with longitudinal welding is a method that has now been tested on a relatively large number of tubes, which probably can be developed into a functioning production method. However, tests with seamless tube manufacturing have yielded such promising results that the immediate focus in tube manufacturing will be on continued testing of extrusion and pierce and draw processing. For now, no new manufacturing of longitudinally welded tubes is planned. In connection with continued activities, new manufacturing tests of tubes with thinner material thickness will be carried out (30 mm in a finished canister).
- The completed manufacturing tests of lids and bottoms in copper have established that manufacturing from forged blanks yields the required results. For the future forging of blanks, the manufacturing of forging tools specially designed for this purpose, has been planned.
- Electron beam welding of bottoms onto copper tubes can probably be further developed into a functioning production method. Welding using purpose-built welding equipment with reduced pressure, has not yet been undertaken. The Canister Laboratory will be able to manage this.
- The casting of inserts in nodular iron with integrated bottoms will, in all likelihood, be managed in serial production maintaining a good and even quality. The continued manufacturing will be carried out in accordance with the developed design, which includes “cooling tubes” as described above for both BWR and PWR inserts.
- For insert lids, the current design involving conical circumference as described above seems to provide the most suitable solution. Testing of this design will be continued.
- A quality assurance system for canister manufacturing in accordance with ISO 9001 requirements, has been developed and is gradually being implemented. Important work that needs to be undertaken in connection with quality control, is that of determining acceptance criteria for all canister components, as well as developing and determining necessary testing methods. A special plan concerning this work will be determined.
- An initial study regarding the possible design of a canister factory has been undertaken. The work concerning this will continue, focusing on a more detailed design.

9 References

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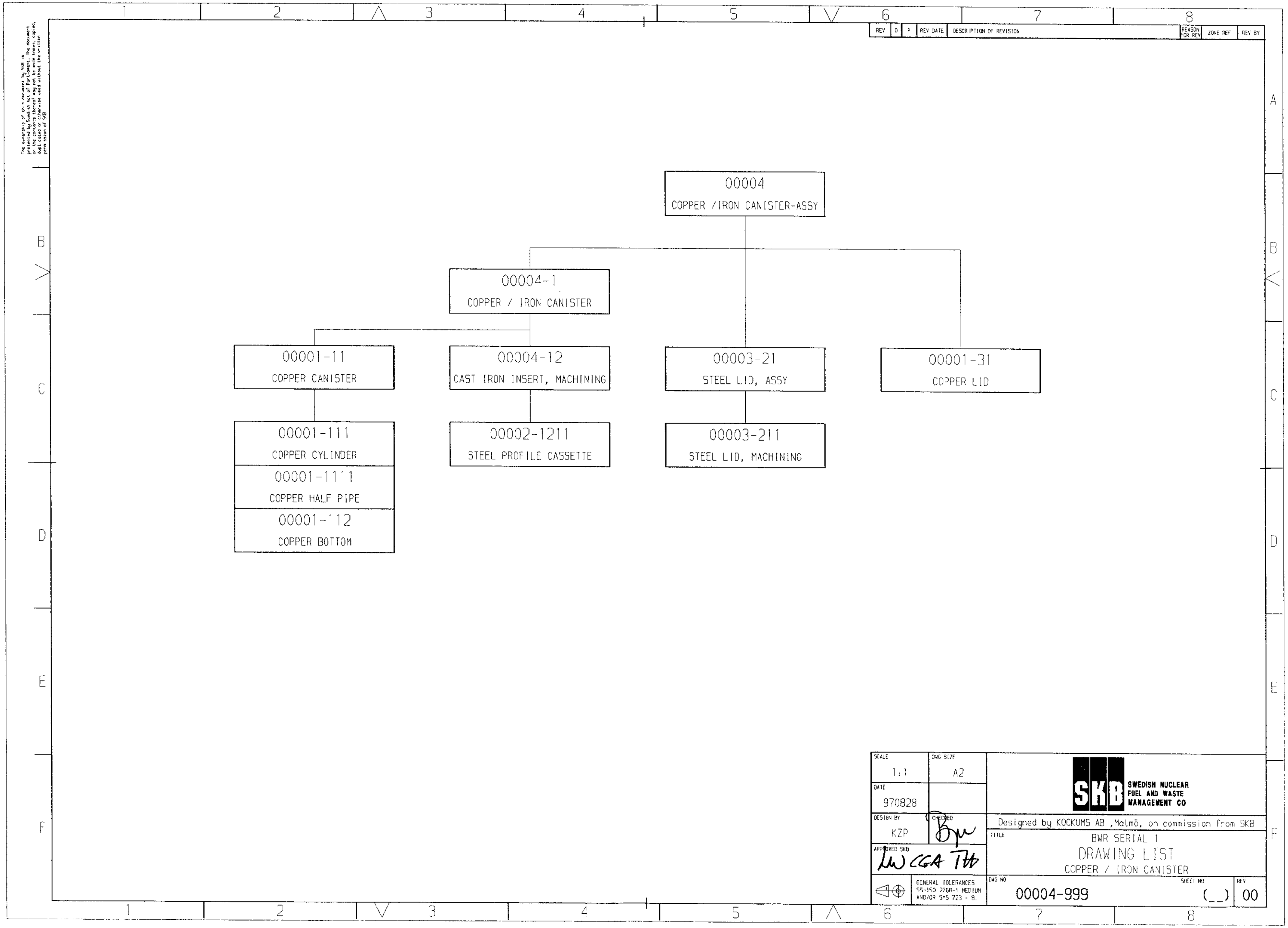

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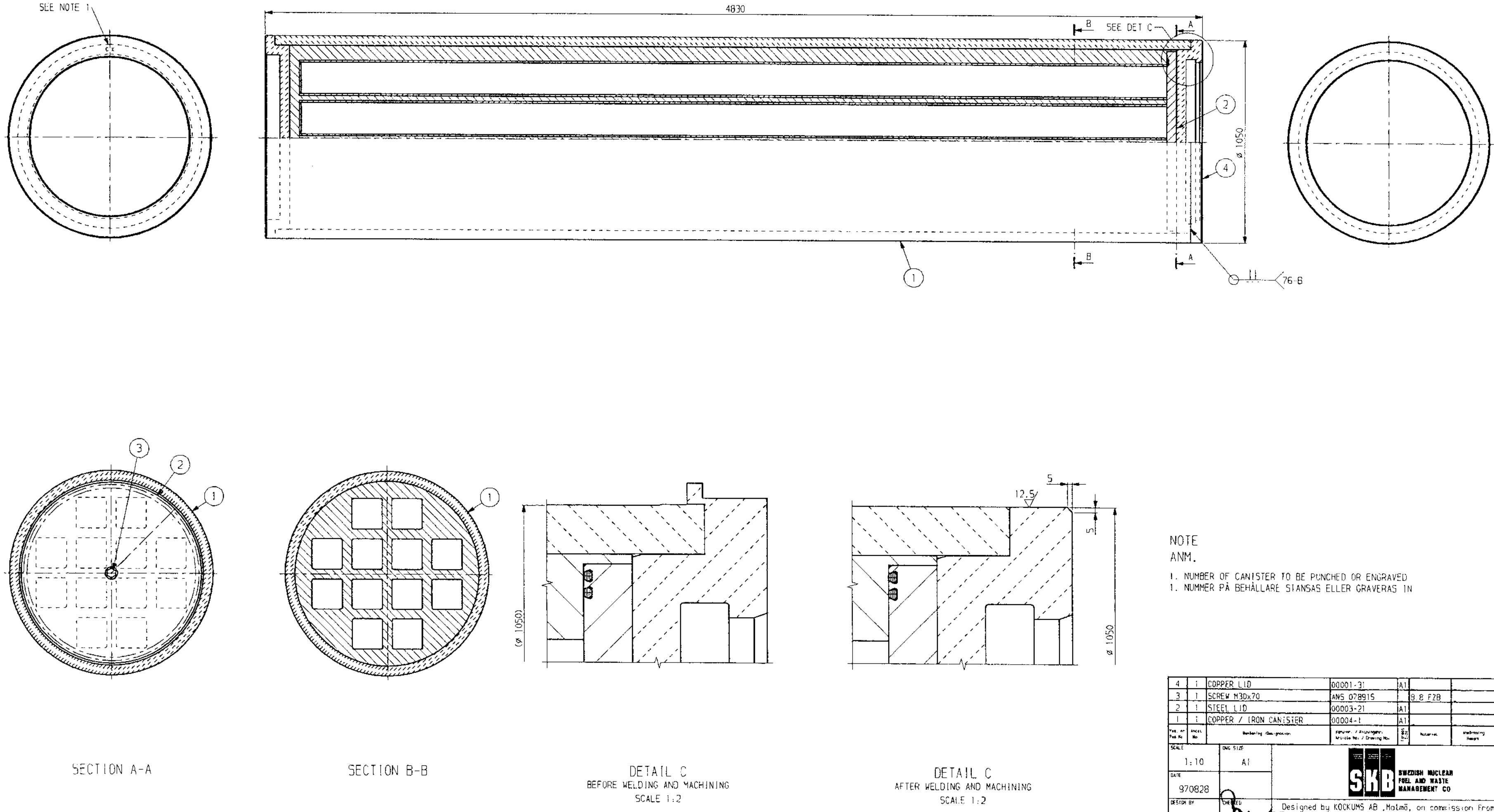

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SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

Designed by KOCKUMS AB, Malmö, on commission from SKB

TITLE BWR SERIAL 1
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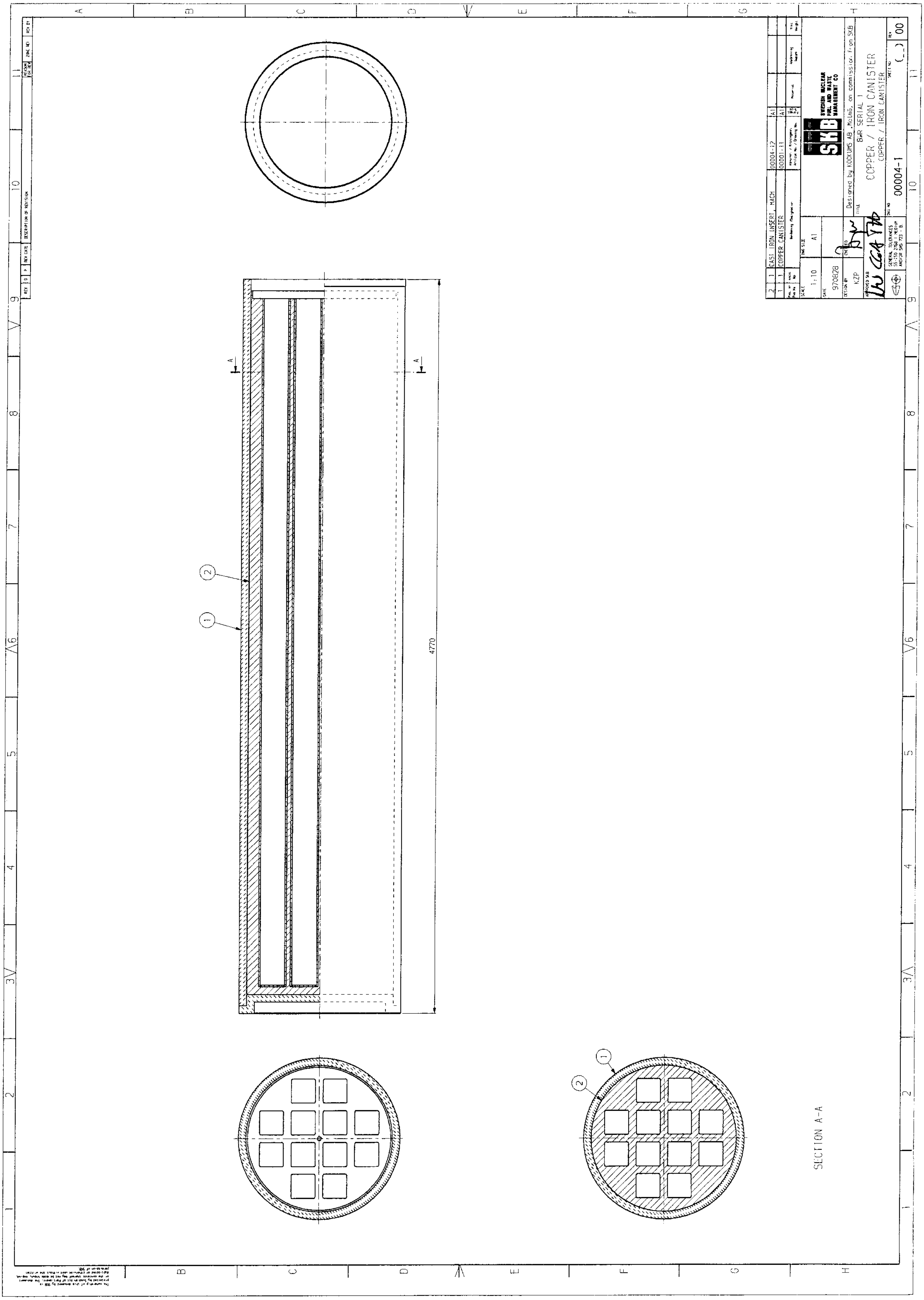

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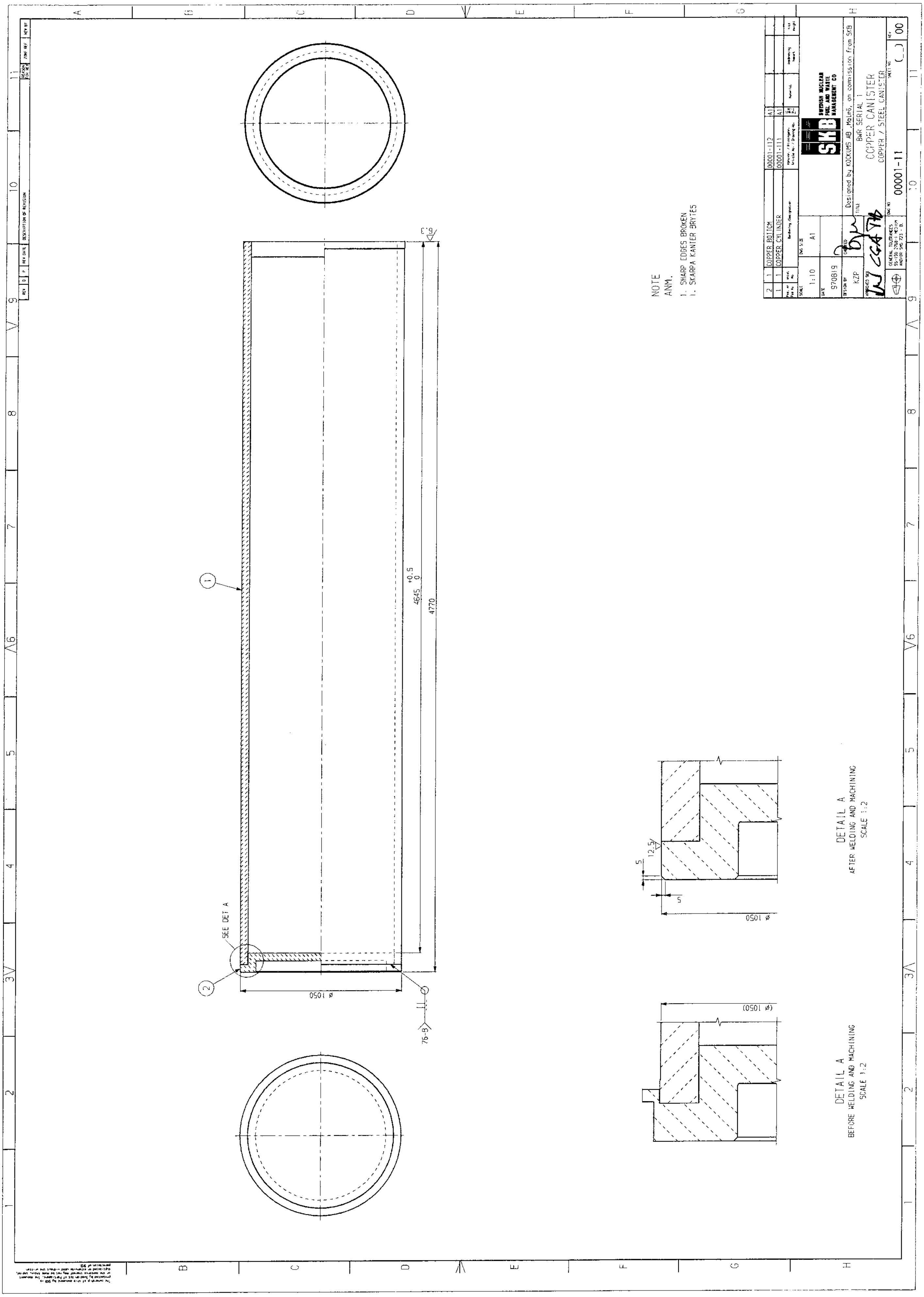
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SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
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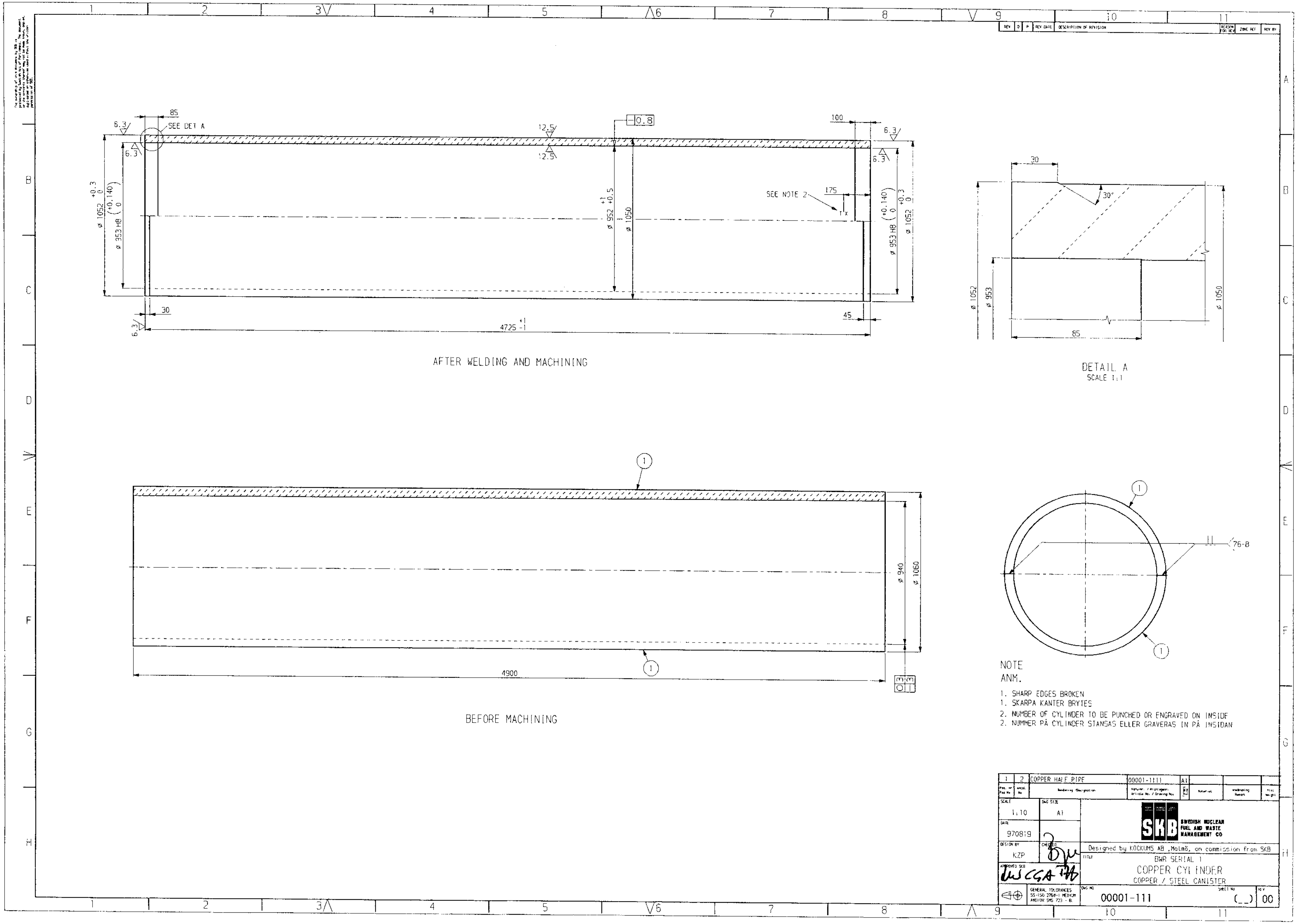
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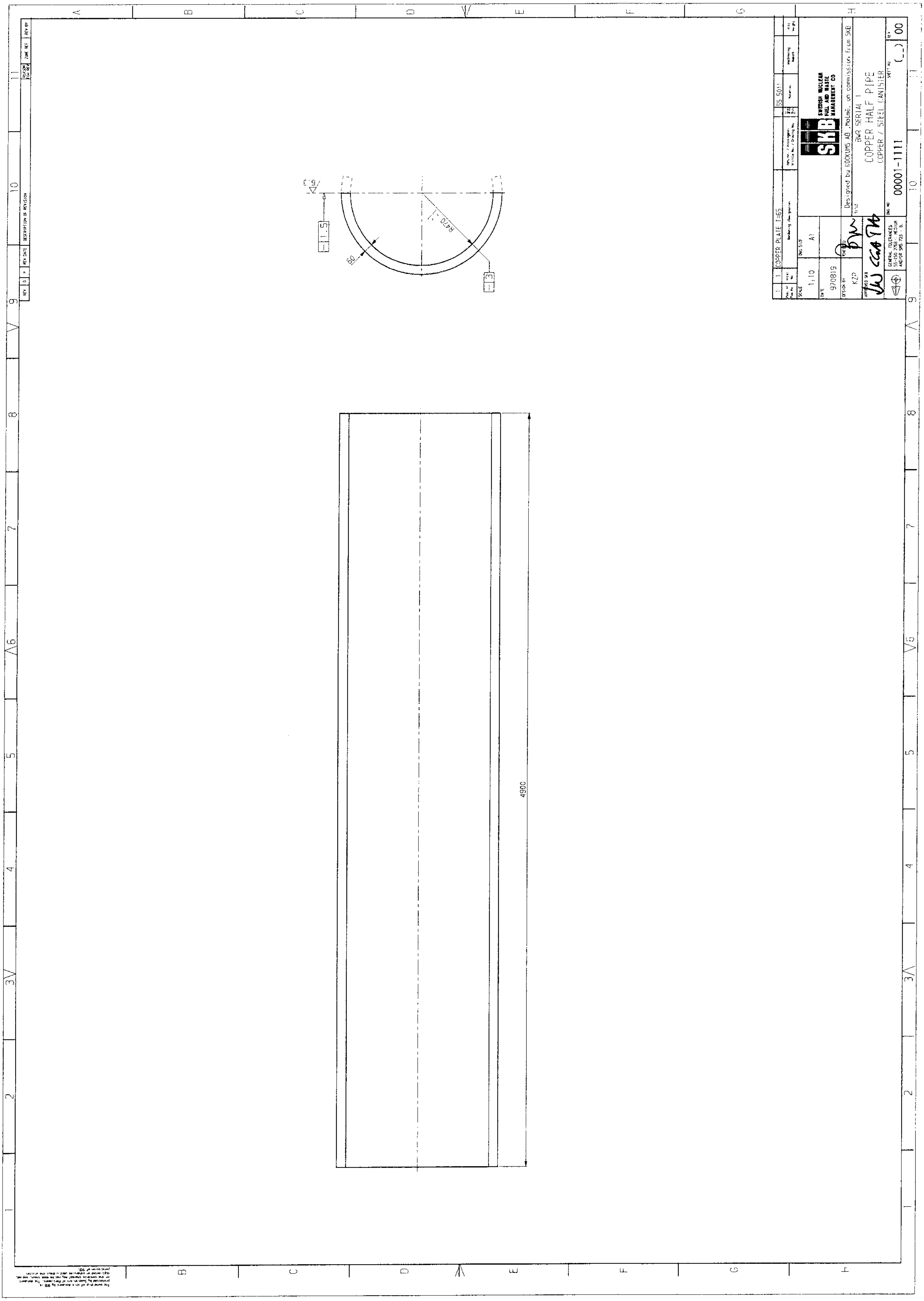
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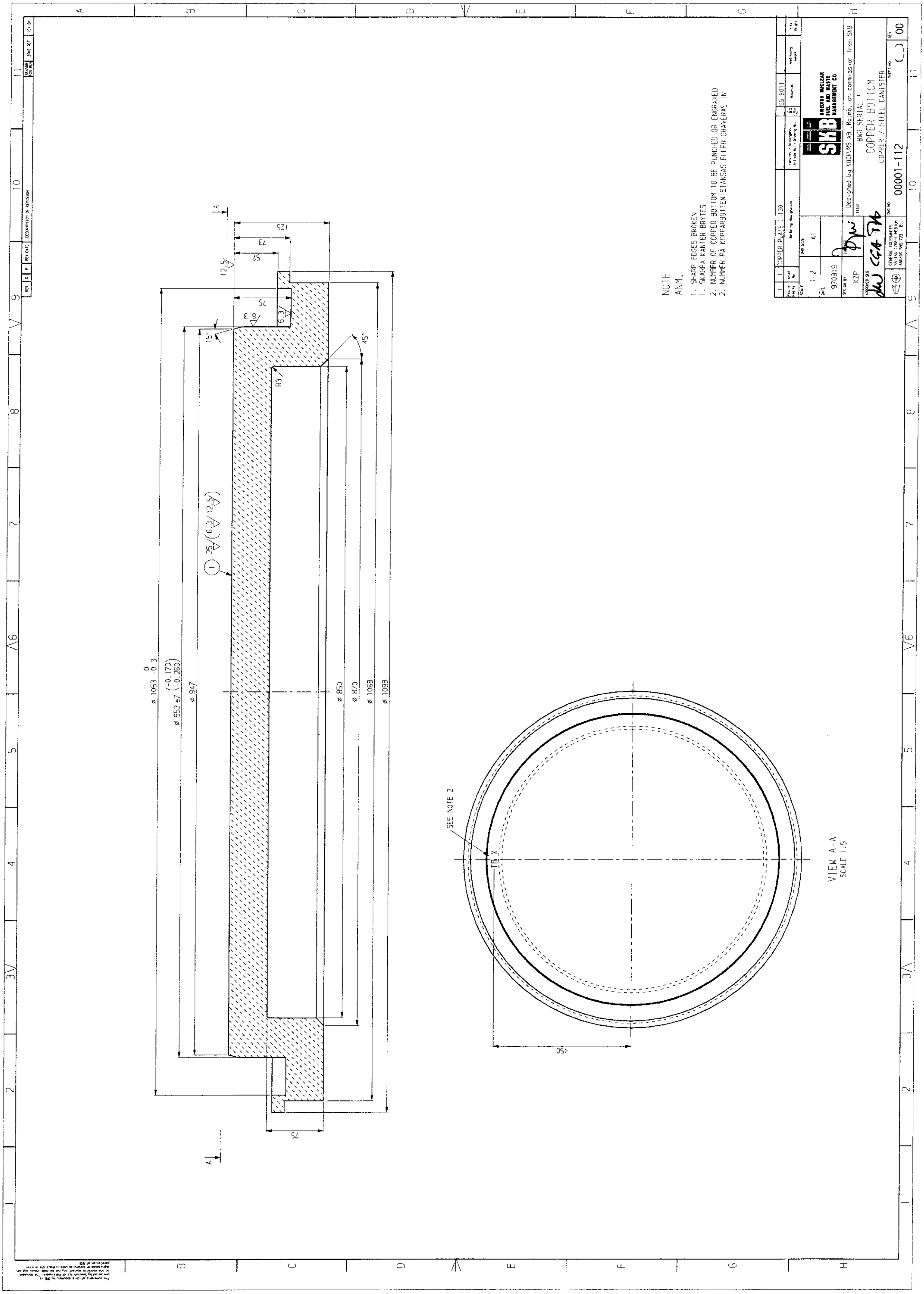
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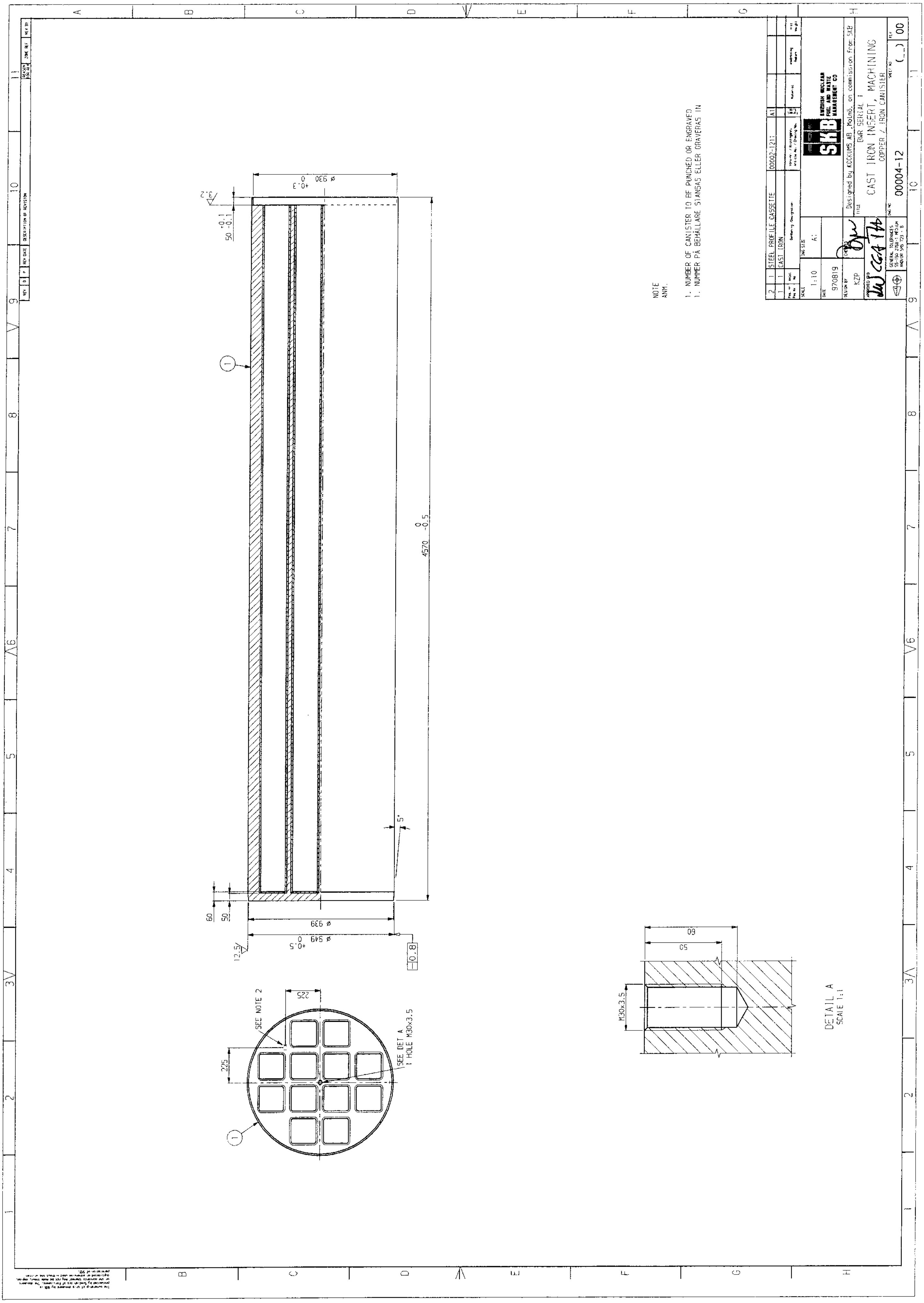
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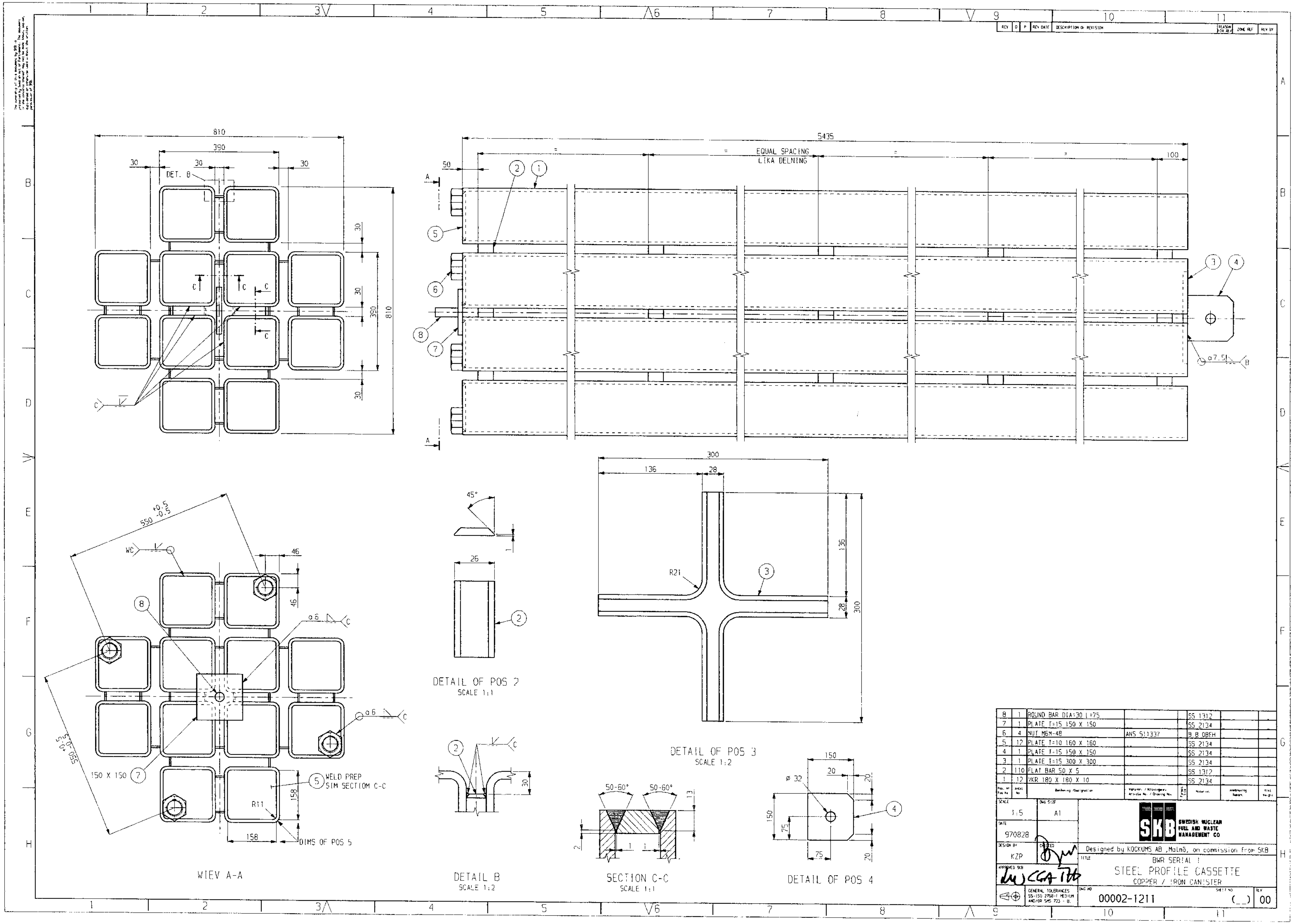
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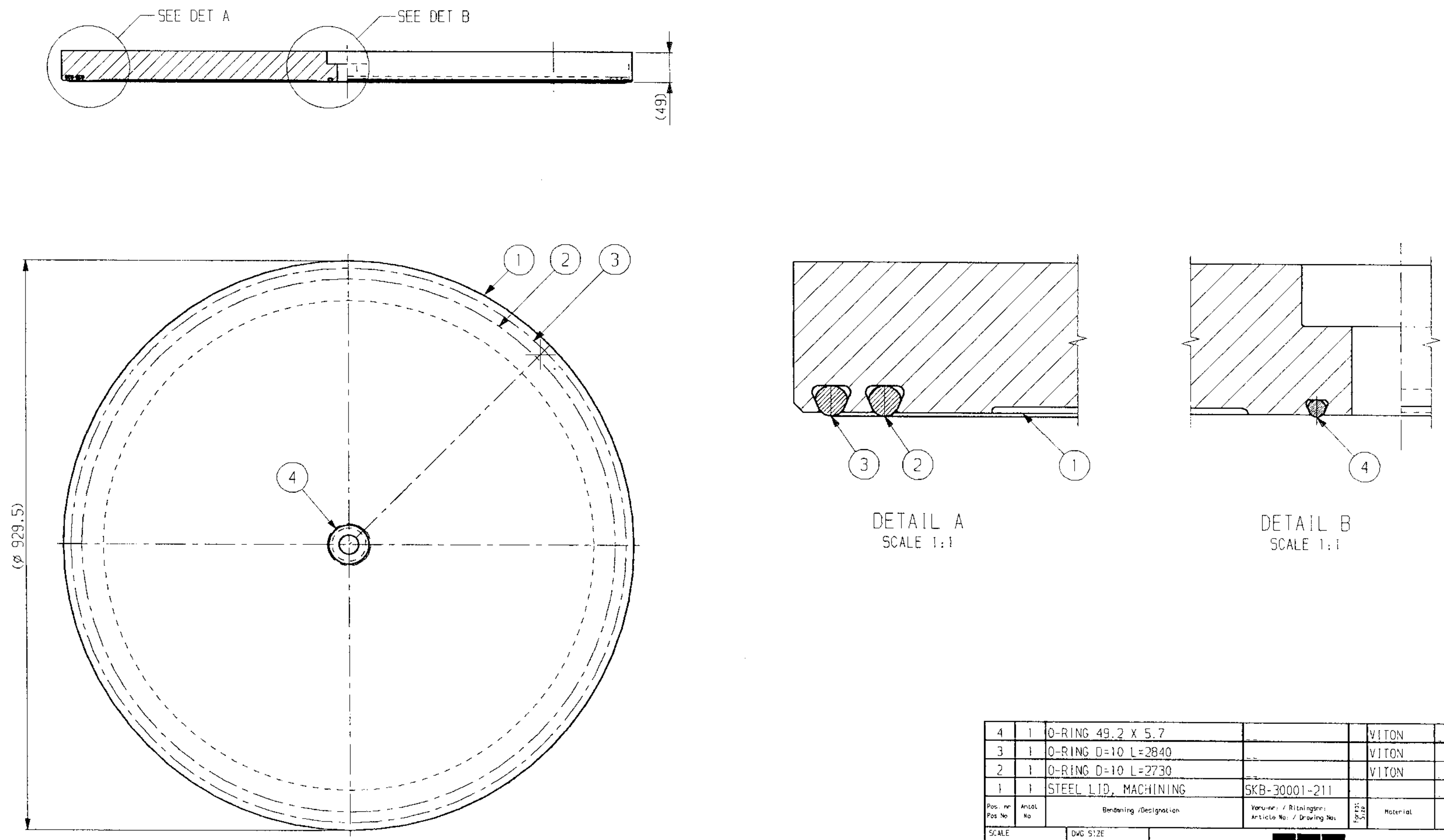

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APPROVED SKB

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

Designed by KOCKUMS AB ,Malmö, on commission from SKB

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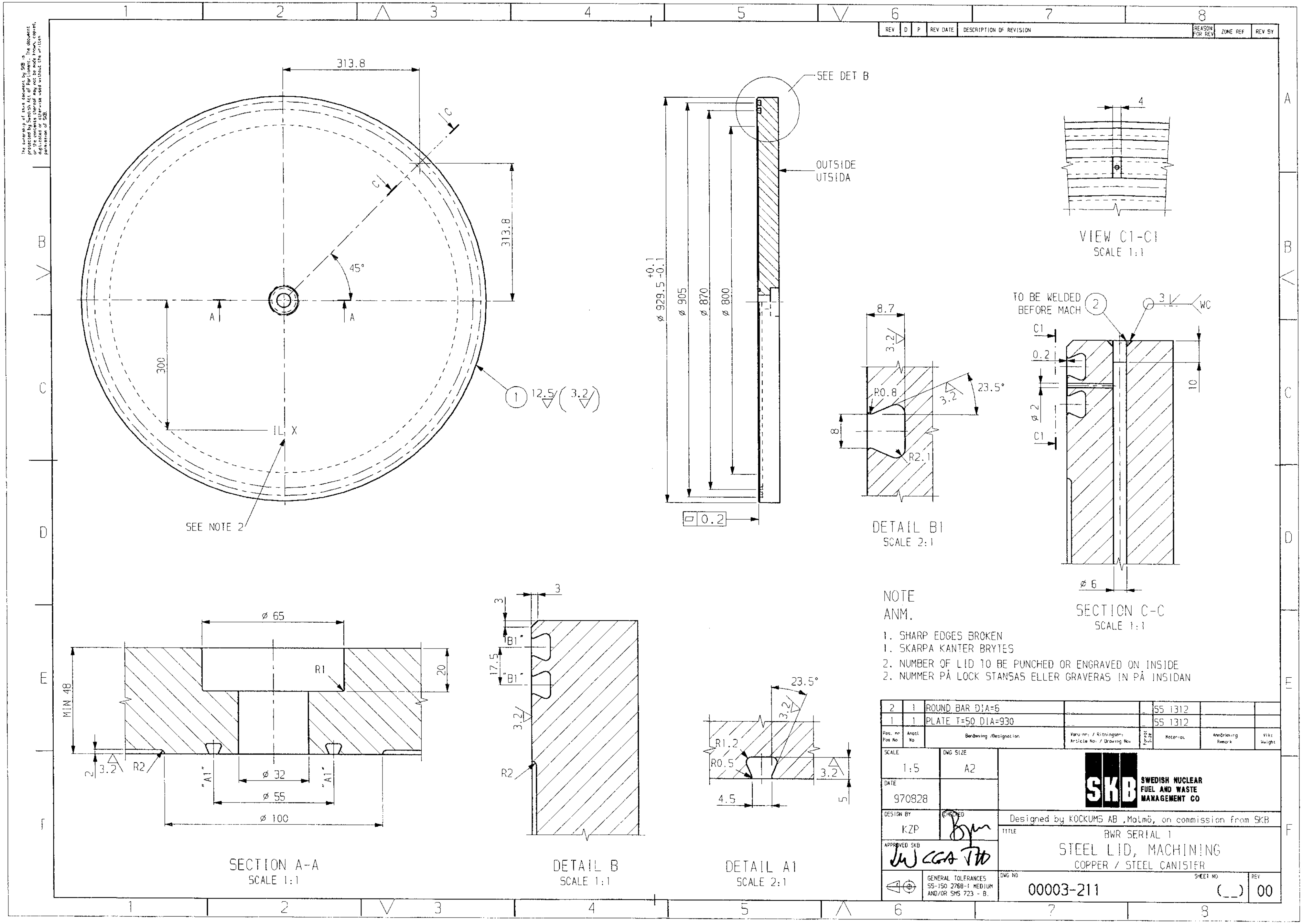

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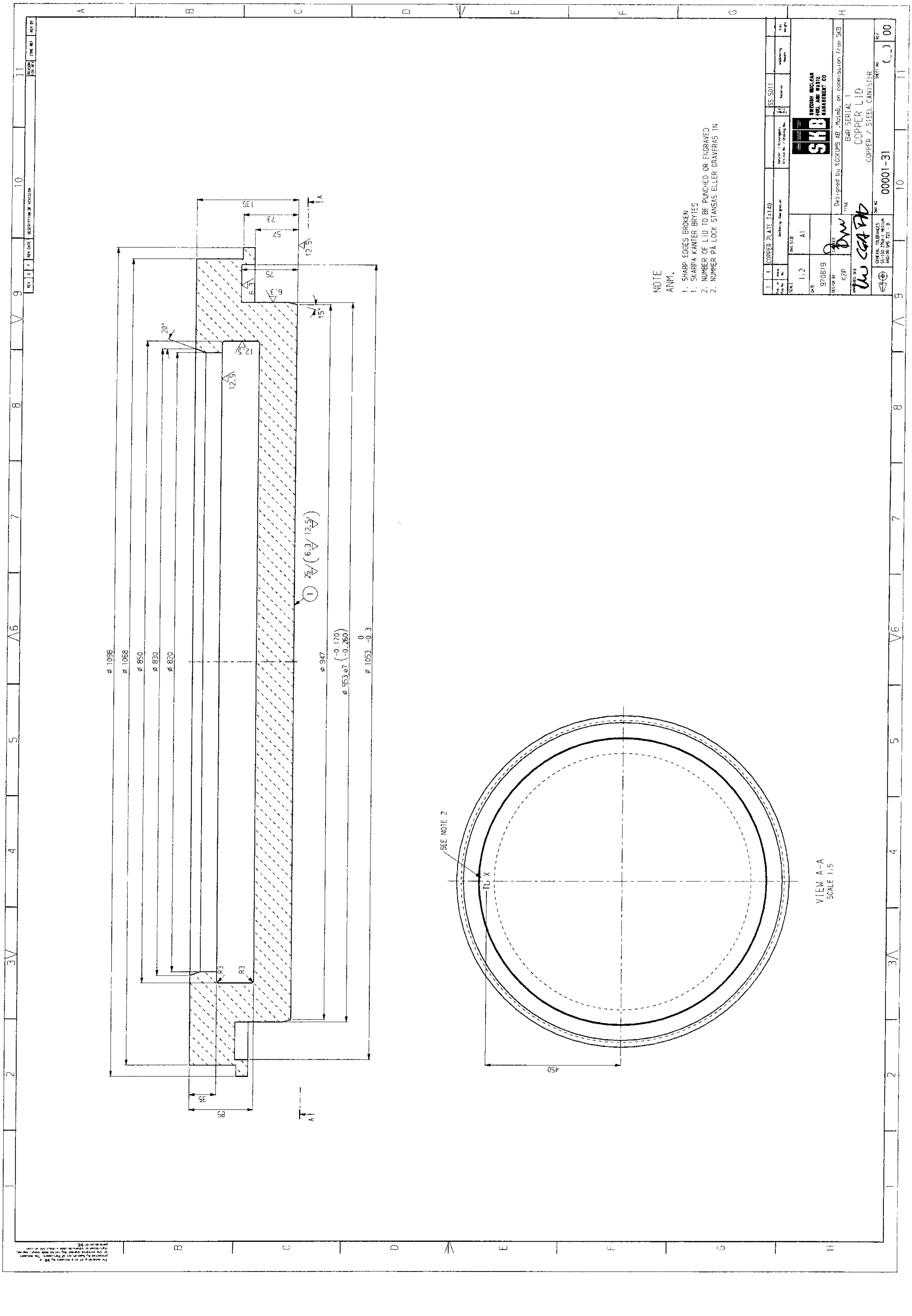
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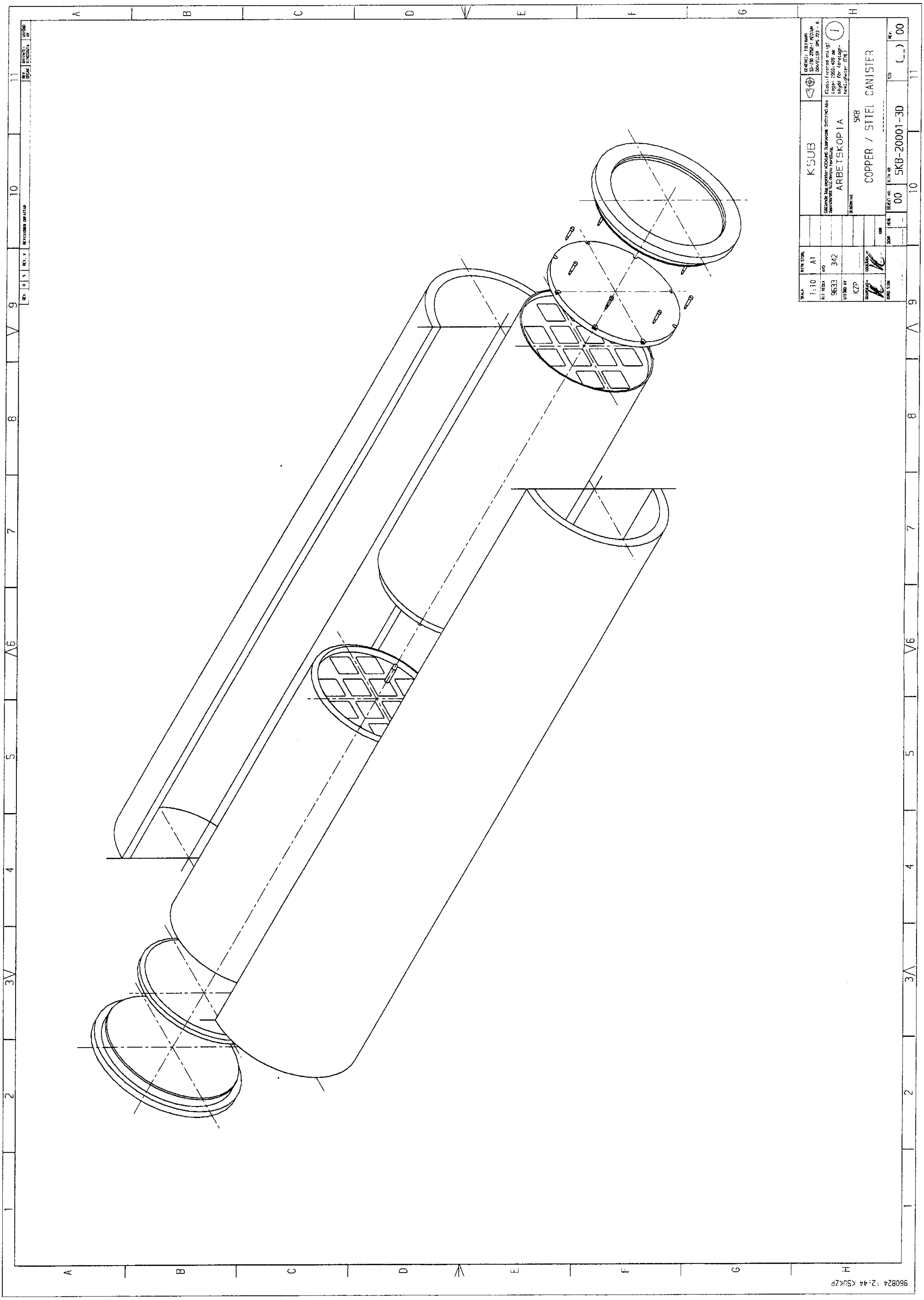
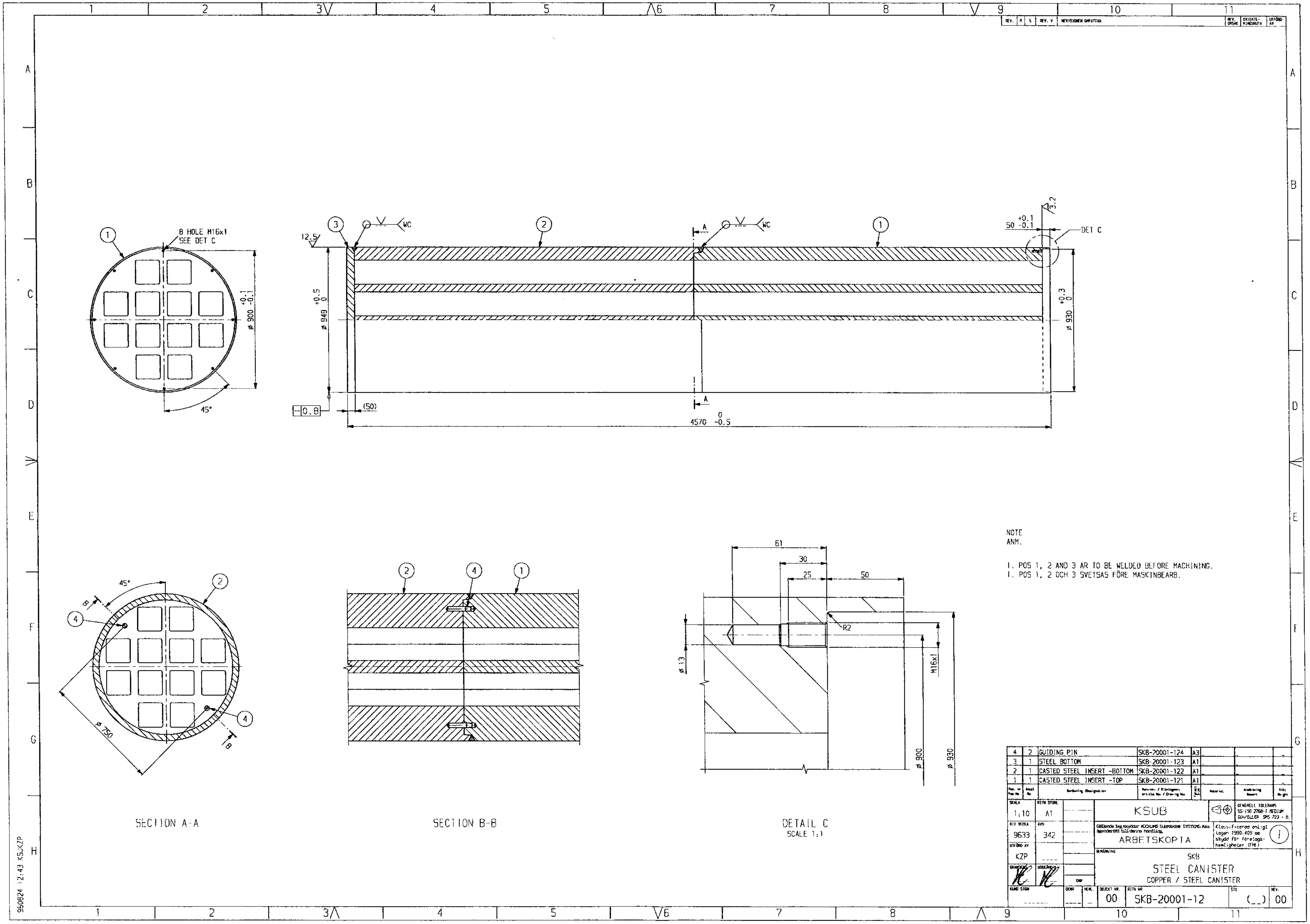
K2P
Designed by KOCKUMS AB, Malmö, on commission from SKB
BWR SERIAL 1
COPPER LID
COPPER / STEEL CANISTER
00001-31
00
ø 1098
ø 1068
ø 850
ø 830
ø 820
ø 947
ø 953 e7
ø 1053
135
73
57
75
35
85
450


KSUB
ARBETSKOPIA
SKB
COPPER / STTEL CANISTER
SKB-20001-3D
1:10
A1
9633
342
KZP
00
00
960824 12:44 KSUKZP



8 HOLE M16x1
SEE DET C
ø 900 +0.1 -0.1
45°
ø 949 +0.5 0
12.5
WC
A
50 +0.1 -0.1
3.2
DET C
ø 930 +0.3 0
0.8
(50)
4570 0 -0.5
NOTE
ANM.
1. POS 1, 2 AND 3 AR TO BE WELDED BEFORE MACHINING.
1. POS 1, 2 OCH 3 SVETSAS FÖRE MASKINBEARB.
ø 750
B
61
30
25
50
R2
ø 13
M16x1
ø 900
ø 930
SECTION A-A
SECTION B-B
DETAIL C
SCALE 1:1
4 2 GUIDING PIN SKB-20001-124 A3
3 1 STEEL BOTTOM SKB-20001-123 A1
2 1 CASTED STEEL INSERT -BOTTOM SKB-20001-122 A1
1 1 CASTED STEEL INSERT -TOP SKB-20001-121 A1
SKALA 1:10
RITN STORL A1
RIT VECKA 9633
AVD 342
UTFÖRD AV KZP
KSUB
GENERELL TOLERANS SS-ISO 2768-1 MEDIUM OCH/ELLER SMS 723 - B.
ARBETSKOPIA
Klassificerad enligt lagen 1990:409 om skydd för företagshemligheter (FHL)
SKB
STEEL CANISTER
COPPER / STEEL CANISTER
OBJEKT NR. 00
RITN NR SKB-20001-12
REV. 00
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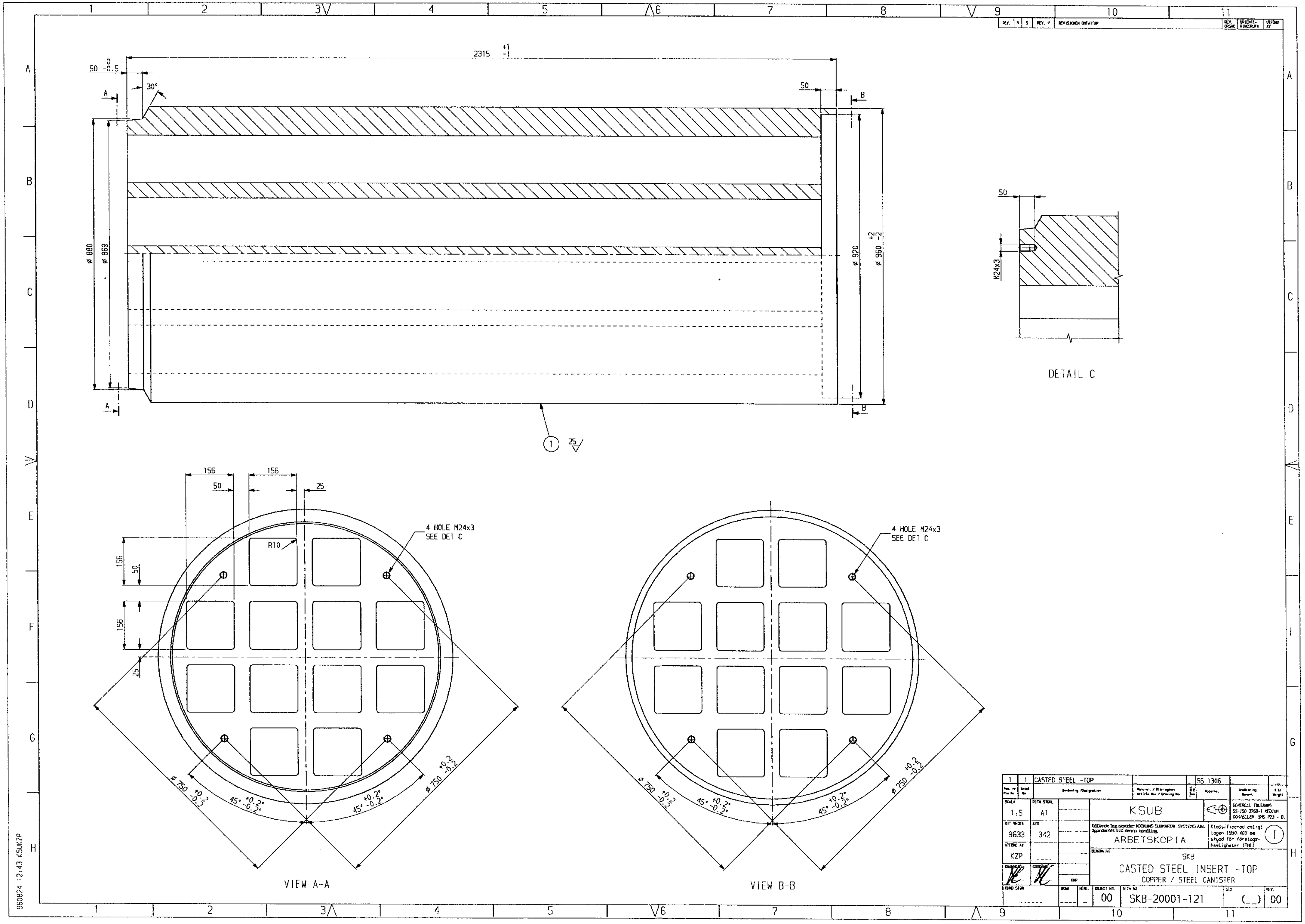
2315 +1 -1
50 0 -0.5
30°
50
ø 880
ø 869
ø 920
ø 960 +2 -2
25
DETAIL C
M24x3
4 HOLE M24x3
SEE DET C
156
50
25
R10
ø 750 +0.2 -0.2
45° +0.2° -0.2°
VIEW A-A
VIEW B-B
CASTED STEEL -TOP
55 1306
1:5
A1
KSUB
9633
342
ARBETSKOPIA
KZP
SKB
CASTED STEEL INSERT -TOP
COPPER / STEEL CANISTER
00
SKB-20001-121
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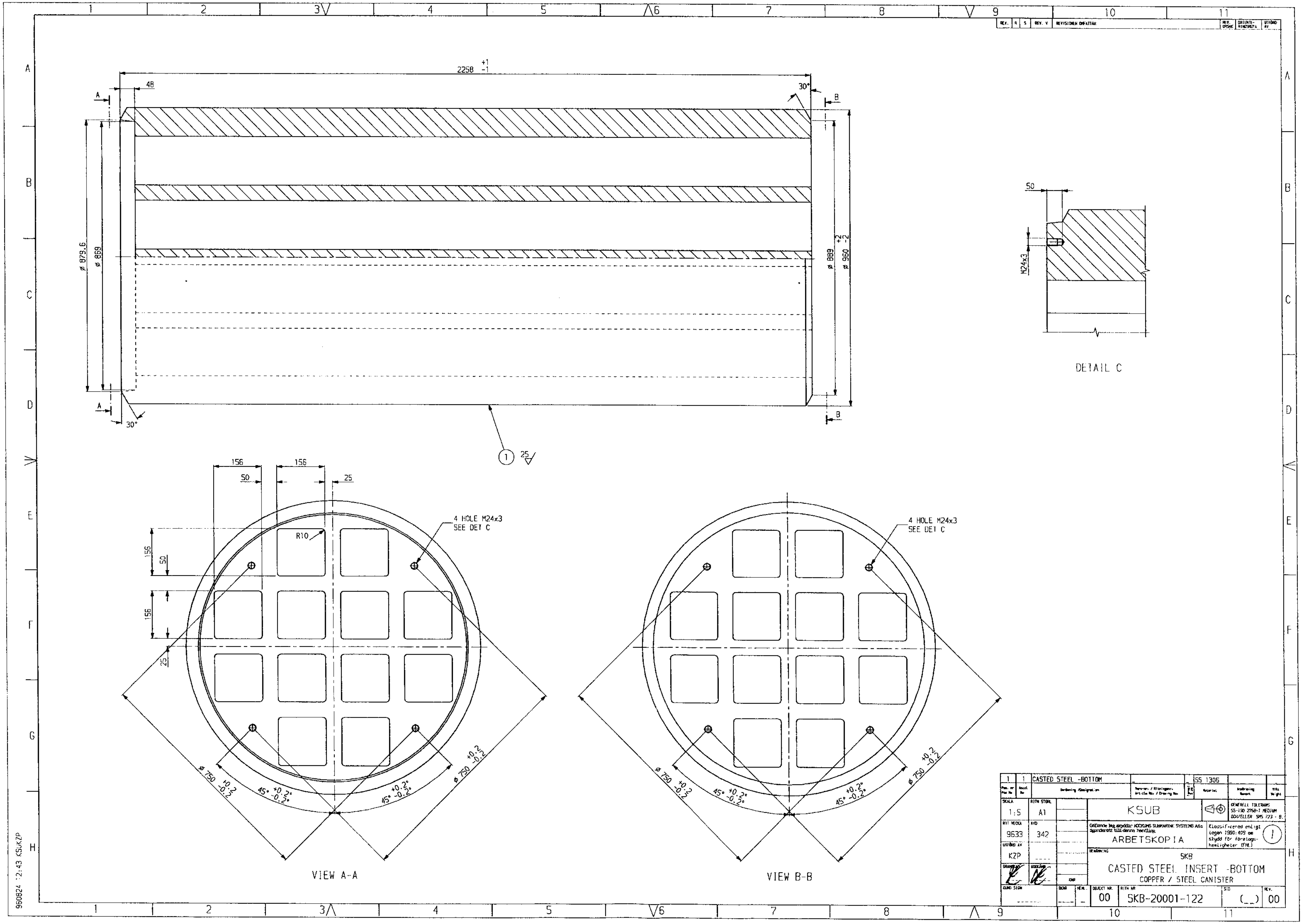
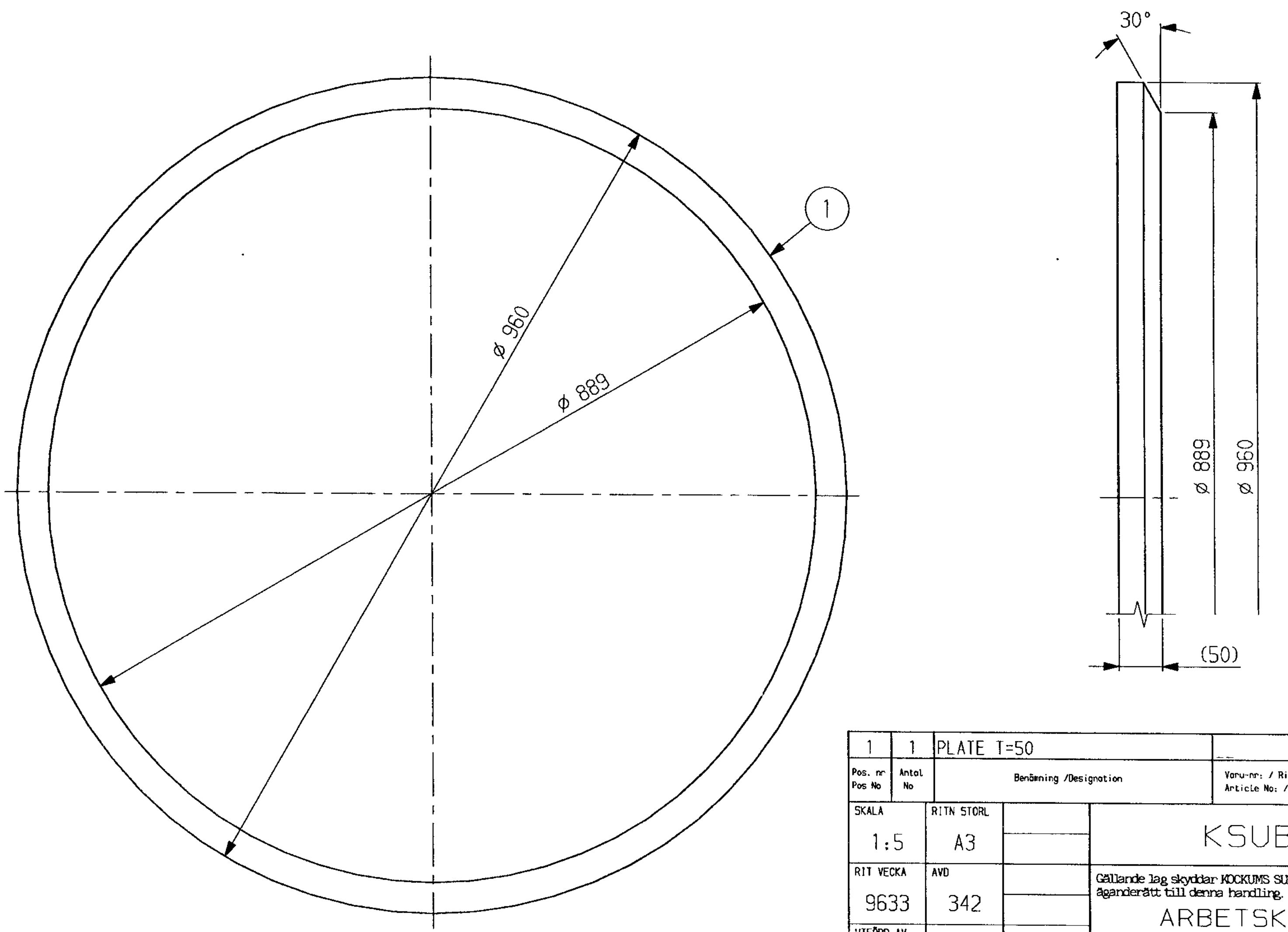

2258 +1 -1
48
30°
ø 879.6
ø 869
ø 889 +2
ø 960 -2
DETAIL C
50
M24x3
156
50
25
R10
4 HOLE M24x3
SEE DET C
ø 750 +0.2 -0.2
45° +0.2° -0.2°
VIEW A-A
VIEW B-B
CASTED STEEL -BOTTOM
SS 1305
1:5
A1
KSUB
ARBETSKOPIA
9633
342
KZP
SKB
CASTED STEEL INSERT -BOTTOM
COPPER / STEEL CANISTER
00
SKB-20001-122
00
960824 12:43 KSUKZP



REV.	R	S	REV. V	REVISIONEN OMFATTAR	REV. ORSAK	ORIENTE-RINGSRUTA	UTFÖRD AV

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1	1	PLATE T=50	–	–	SS 1312	–	–

SKALA	1:5
RITN STORL	A3
RIT VECKA	9633
AVD	342
UTFÖRD AV	KZP
GRANSKAD	[signature]
GODKÄND	[signature]
KNR	
KUND SIGN	------
DKNR	----
HEML.	–
OBJEKT NR.	00
RITN NR	SKB-20001-123
SID	(__)
REV.	00

KSUB

GENERELL TOLERANS SS-ISO 2768-1 MEDIUM OCH/ELLER SMS 723 - B.

Gällande lag skyddar KOCKUMS SUBMARINE SYSTEMS ABs äganderätt till denna handling.

ARBETSKOPIA

Klassificerad enligt lagen 1990:409 om skydd för företagshemligheter (FHL) — I

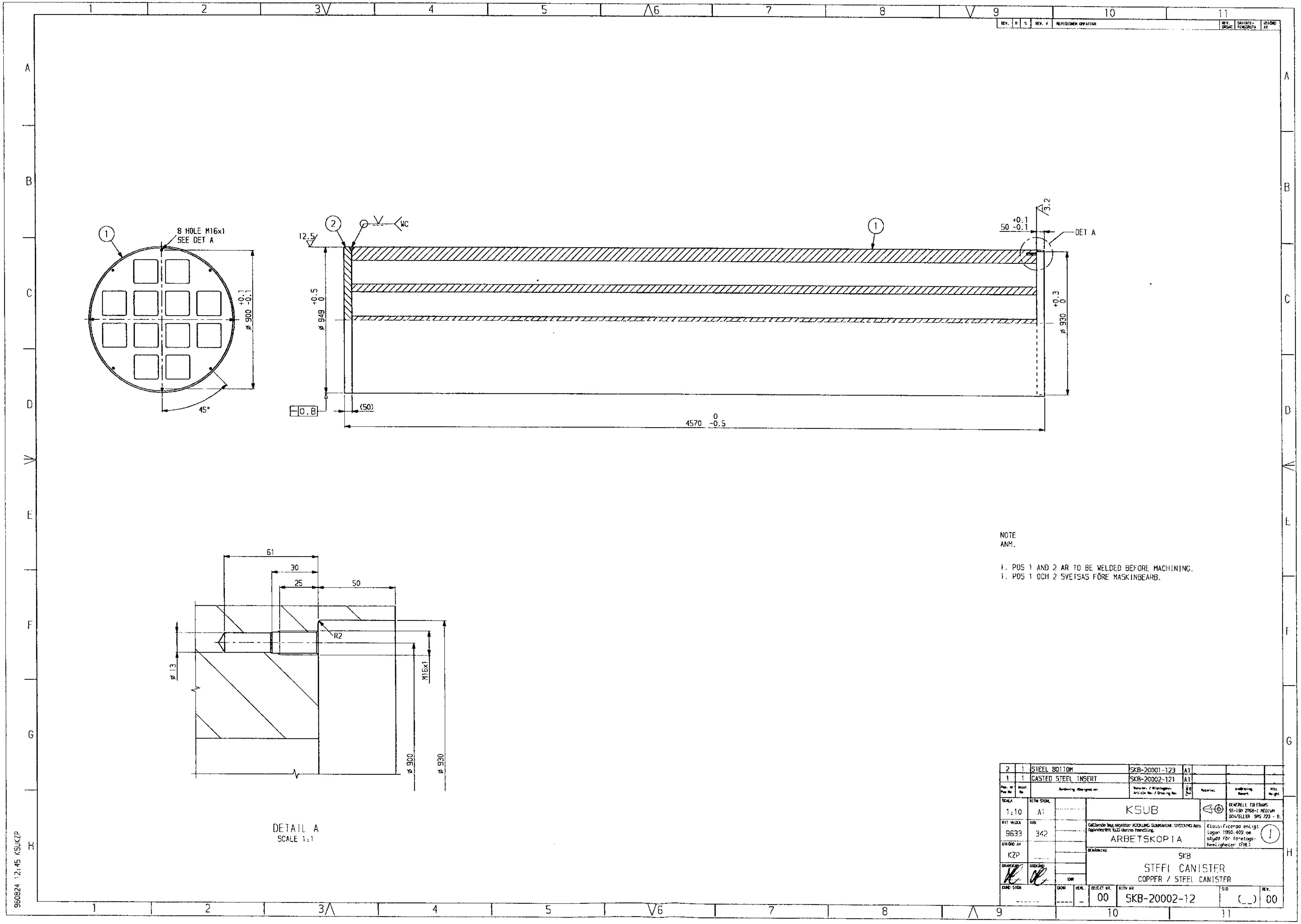
BENÄMNING

SKB

STEEL BOTTOM

COPPER / STEEL CANISTER

960824 12:43 KSUKZP


8 HOLE M16x1
SEE DET A
ø 900 +0.1 -0.1
45°
12.5
WC
ø 949 +0.5 0
0.8
(50)
4570 0 -0.5
50 +0.1 -0.1
3.2
DET A
ø 930 +0.3 0
61
30
25
50
R2
ø 13
M16x1
ø 900
ø 930
DETAIL A
SCALE 1:1
NOTE
ANM.
1. POS 1 AND 2 AR TO BE WELDED BEFORE MACHINING.
1. POS 1 OCH 2 SVETSAS FÖRE MASKINBEARB.
2 1 STEEL BOTTOM SKB-20001-123 A1
1 1 CASTED STEEL INSERT SKB-20002-121 A1
SKALA 1:10
RITN STORL A1
RIT VECKA 9633
AVD 342
UTFÖRD AV KZP
KSUB
GENERELL TOLERANS SS-ISO 2768-1 MEDIUM OCH/ELLER SMS 723 - B.
ARBETSKOPIA
Klassificerad enligt lagen 1990:409 om skydd för företagshemligheter (FHL)
BENÄMNING
SKB
STEEL CANISTER
COPPER / STEEL CANISTER
OBJEKT NR. 00
RITN NR SKB-20002-12
REV. 00
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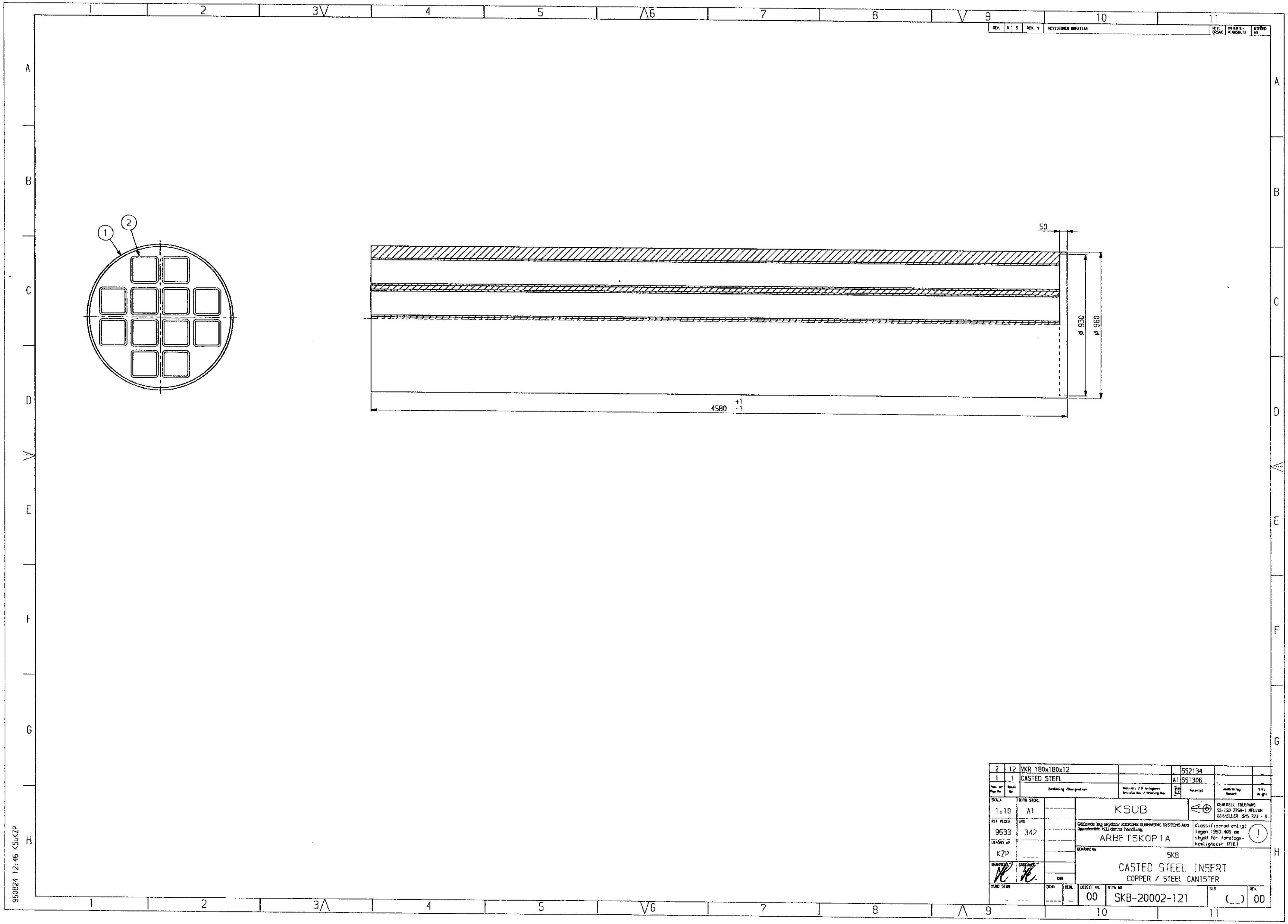
1
2
50
ø 930
ø 960
4580 +1 -1
2 | 12 | VKR 180x180x12 | SS2134
1 | 1 | CASTED STEFL | A1 | SS1306
SKALA 1:10
RITN STORL A1
RIT VECKA 9633
AVD 342
UTFÖRD AV K7P
KSUB
GENERELL TOLERANS SS-ISO 2768-1 MEDIUM OCH/ELLER SMS 723 - 8.
Gällande lag skyddar KOCKUMS SUBMARINE SYSTEMS ABs äganderätt till denna handling.
ARBETSKOPIA
Klassificerad enligt Lagen 1990:409 om skydd för företagshemligheter (FHL)
SKB
CASTED STEEL INSERT
COPPER / STEEL CANISTER
OBJEKT NR. 00
RITN NR SKB-20002-121
REV. 00
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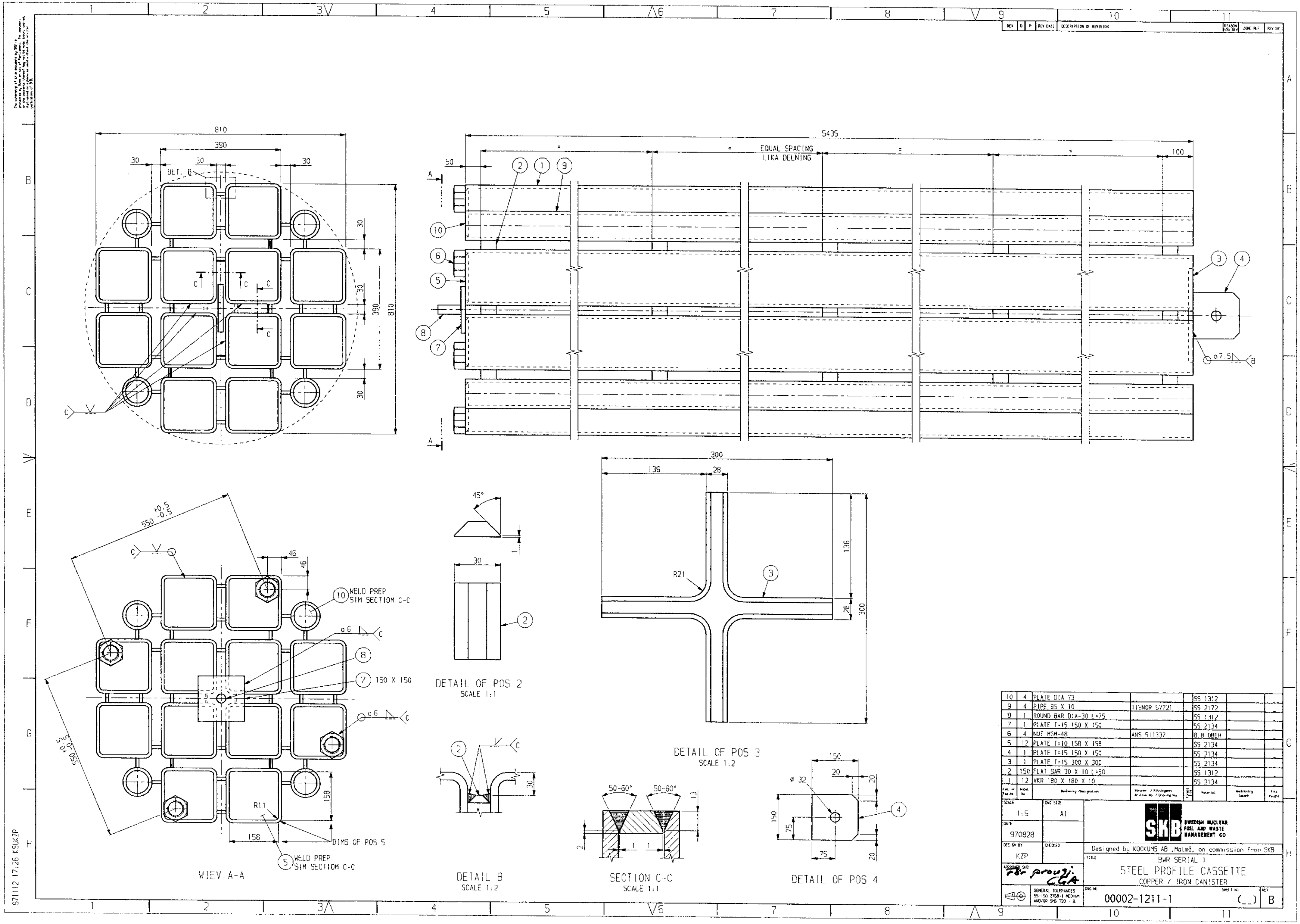

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10	4	PLATE DIA 73			SS 1312		
9	4	PIPE 95 X 10	TIBNOR 57721		SS 2172		
8	1	ROUND BAR DIA=30 L=75			SS 1312		
7	1	PLATE T=15 150 X 150			SS 2134		
6	4	NUT M6M-48	ANS 511337		8.8 OBEH		
5	12	PLATE T=10 158 X 158			SS 2134		
4	1	PLATE T=15 150 X 150			SS 2134		
3	1	PLATE T=15 300 X 300			SS 2134		
2	150	FLAT BAR 30 X 10 L=50			SS 1312		
1	12	VKR 180 X 180 X 10			SS 2134		

SCALE	1:5
DWG SIZE	A1
DATE	970828
DESIGN BY	KZP
CHECKED	
APPROVED SKB	för prov.g. CGA
GENERAL TOLERANCES	SS-ISO 2768-1 MEDIUM AND/OR SMS 723 - B.

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

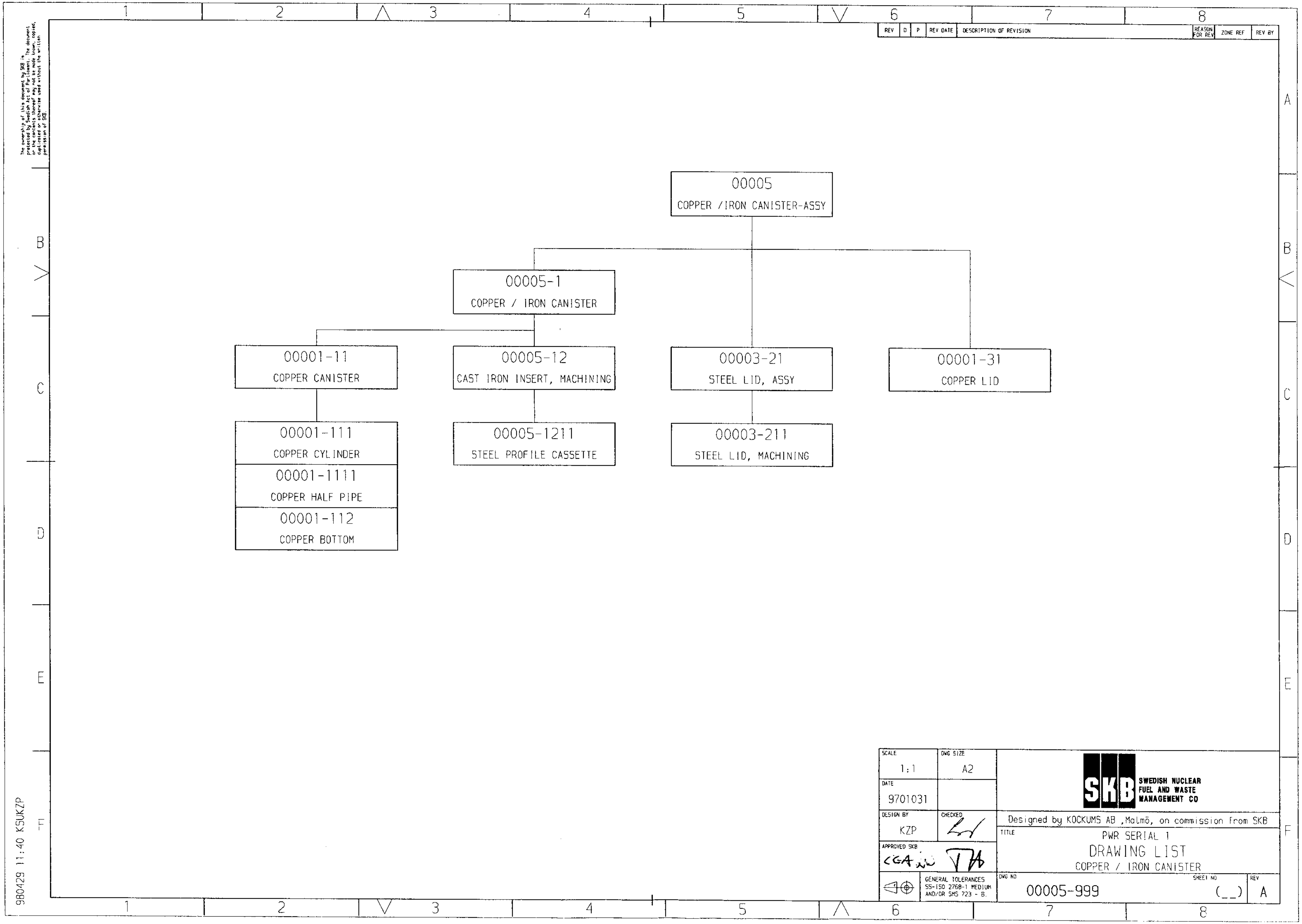
Designed by KOCKUMS AB, Malmö, on commission from SKB

TITLE: BWR SERIAL 1

STEEL PROFILE CASSETTE

COPPER / IRON CANISTER

DWG NO: 00002-1211-1 SHEET NO: (__) REV: B


00005
COPPER /IRON CANISTER-ASSY
00005-1
COPPER / IRON CANISTER
00001-11
COPPER CANISTER
00005-12
CAST IRON INSERT, MACHINING
00003-21
STEEL LID, ASSY
00001-31
COPPER LID
00001-111
COPPER CYLINDER
00001-1111
COPPER HALF PIPE
00001-112
COPPER BOTTOM
00005-1211
STEEL PROFILE CASSETTE
00003-211
STEEL LID, MACHINING
SCALE 1:1
DWG SIZE A2
DATE 9701031
DESIGN BY KZP
CHECKED
APPROVED SKB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
Designed by KOCKUMS AB ,Malmö, on commission from SKB
TITLE
PWR SERIAL 1
DRAWING LIST
COPPER / IRON CANISTER
GENERAL TOLERANCES SS-ISO 2768-1 MEDIUM AND/OR SMS 723 - B.
DWG NO 00005-999
SHEET NO (__)
REV A
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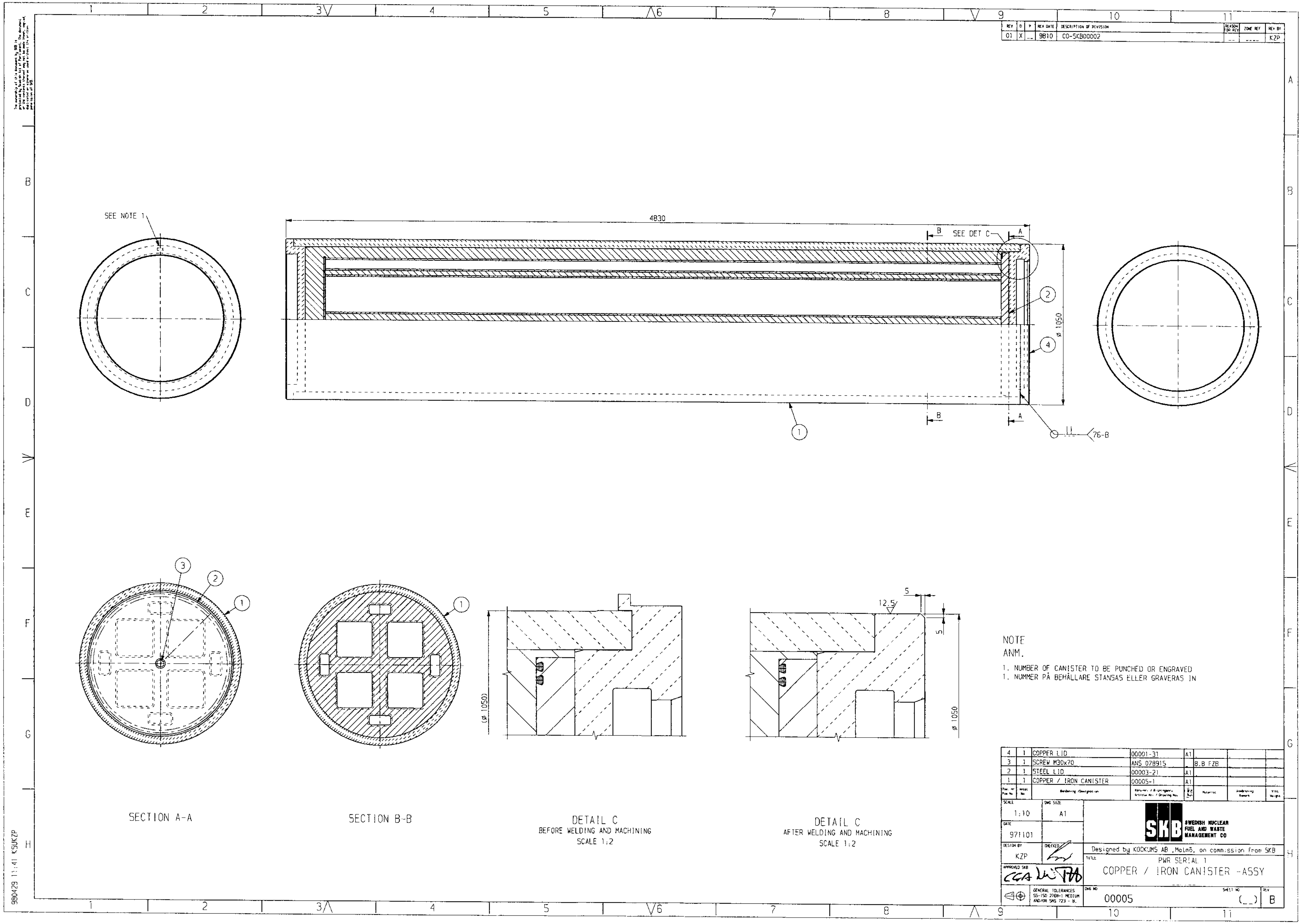
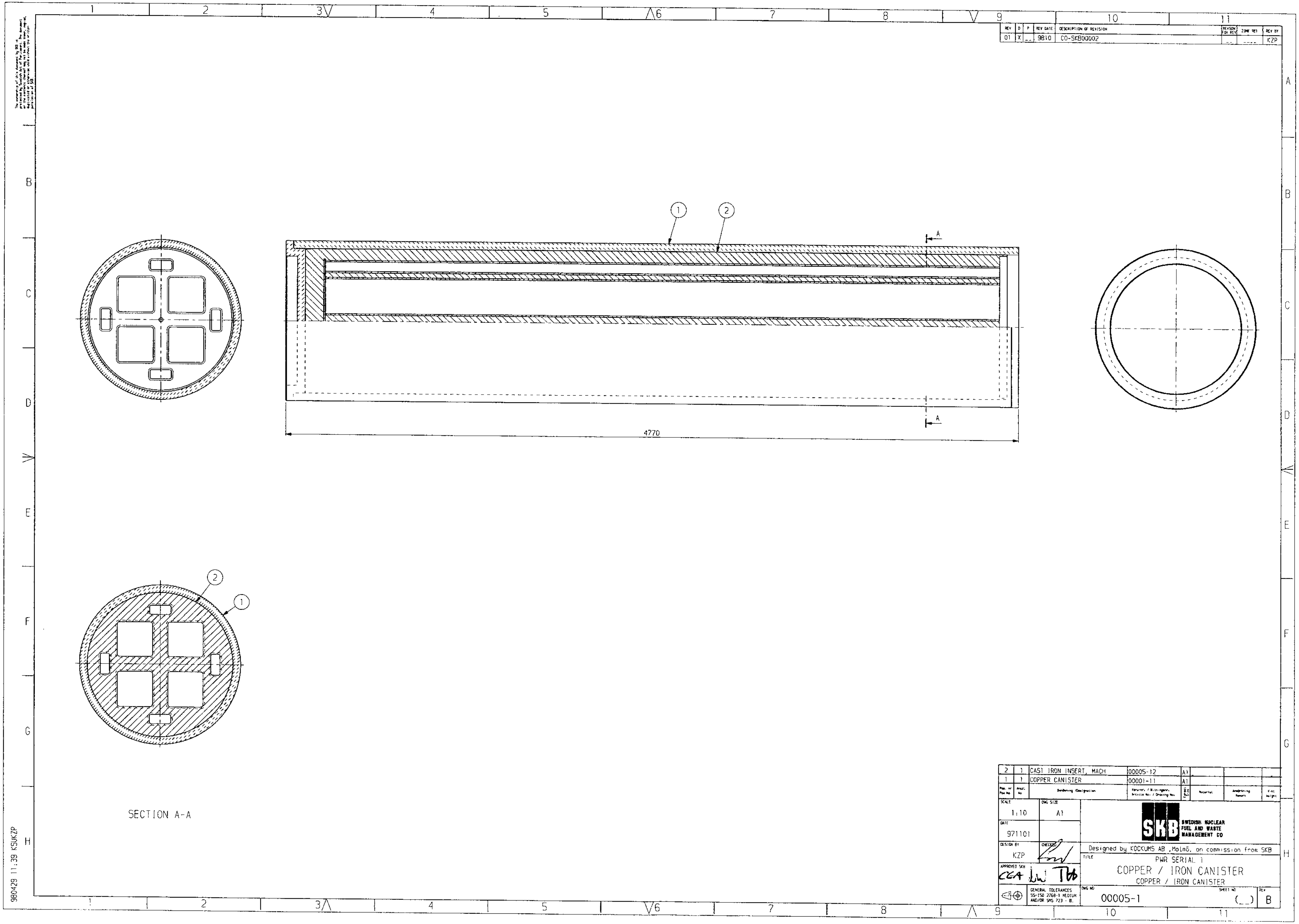


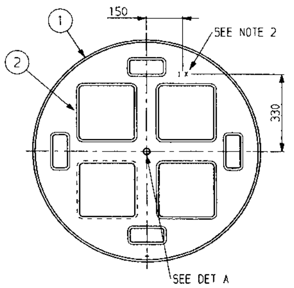
Pos. nr / Pos No	Antal / No	Benämning / Designation	Artikel nr / Ritningsnr / Article No / Drawing No		Material	Anmärkning / Remark	Vikt / Weight
4	1	COPPER LID	00001-31	A1			
3	1	SCREW M30x70	ANS 078915		8.8 FZB		
2	1	STEEL LID	00003-21	A1			
1	1	COPPER / IRON CANISTER	00005-1	A1			

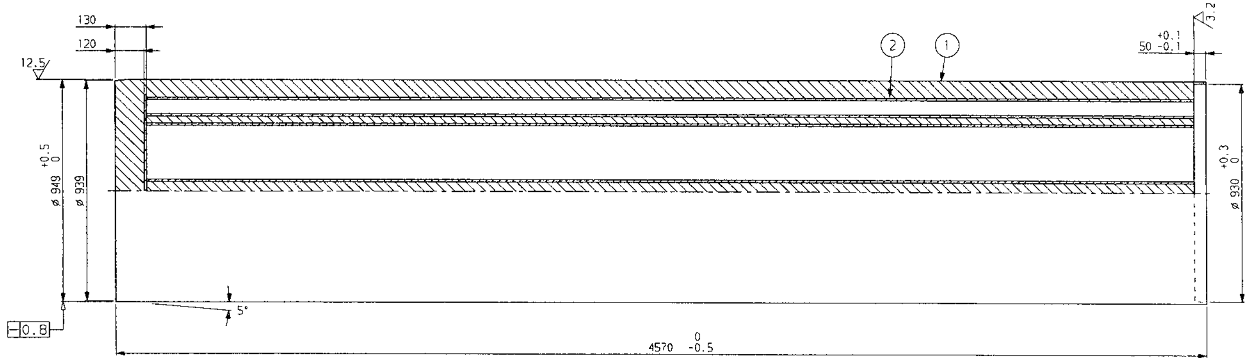
Appendix 4, page 2 (5)

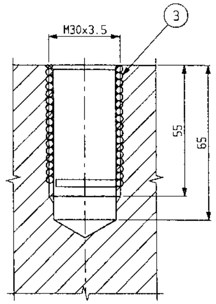


Appendix 4, page 3 (5)

REV	D	P	REV DATE	DESCRIPTION OF REVISION	REASON FOR REV	ZONE REF	REV BY
01	X	__	9810	CO-SKB00002	--	----	KZP







DETAIL A
SCALE 1:1

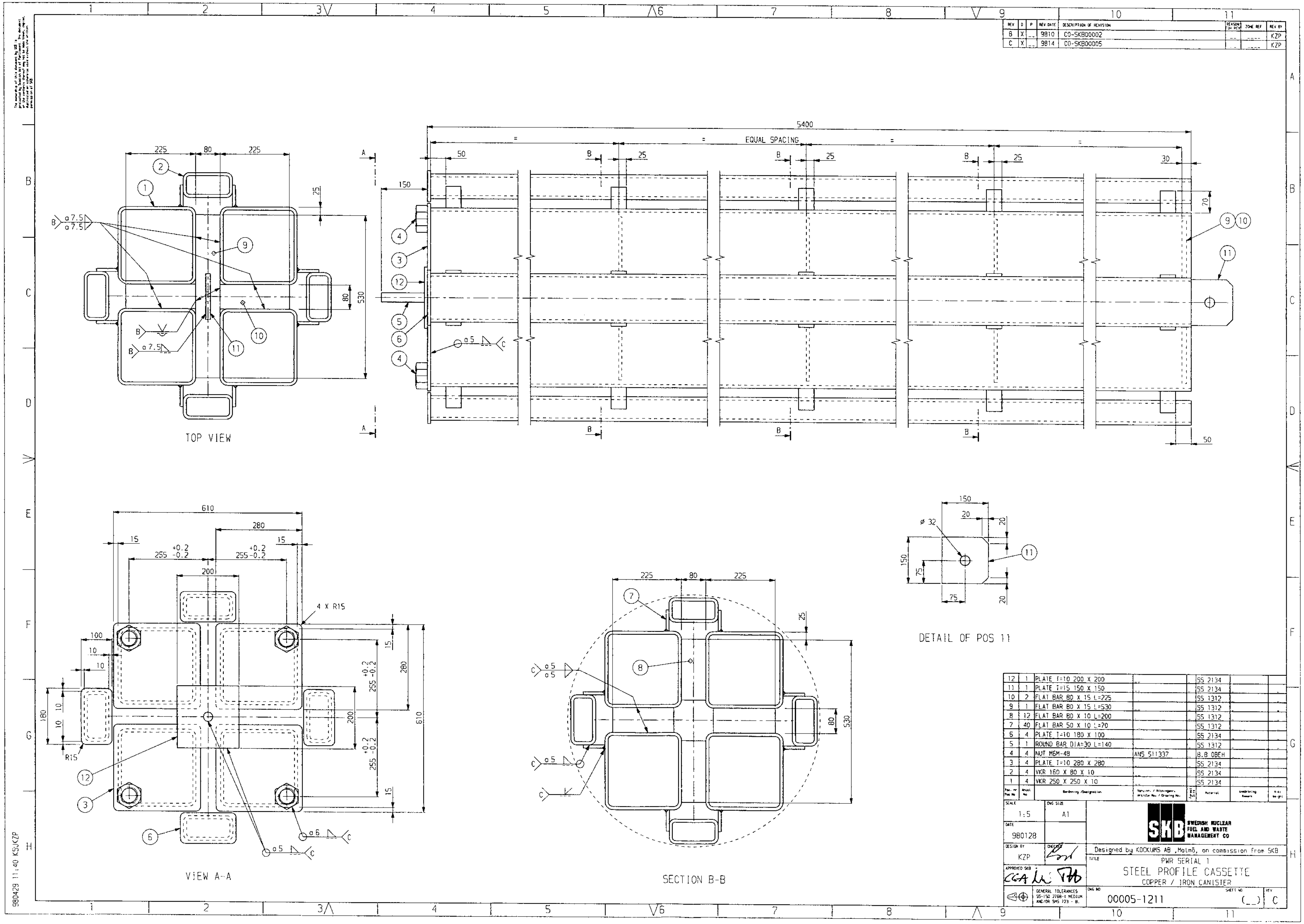
NOTE
ANM.

1. NUMBER OF CANISTER TO BE PUNCHED OR ENGRAVED
1. NUMMER PÅ BEHÅLLARE STANSAS ELLER GRAVERAS IN

Pos. Nr / Pos No	Antal / No	Benämning /Designation	Förnr. / Ritningsnr. / Article No. / Drawing No.		Material	Anmärkning / Remark	Vikt / Weight
3	1	HELI-COIL INSATS M30X3X48		A1	18/8		
2	1	STEEL PROFILE CASSETTE	00005-1211	A1			
1	1	CAST IRON					

SCALE 1:10	DWG SIZE A1	SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
DATE 971101		
DESIGN BY KZP	CHECKED	Designed by KOCKUMS AB ,Malmö, on commission from SKB
APPROVED SKB		TITLE PWR SERIAL 1 CAST IRON INSERT, MACHINING COPPER / IRON CANISTER
	GENERAL TOLERANCES SS-ISO 2768-1 MEDIUM AND/OR SMS 723 - B.	DWG NO 00005-12 — SHEET NO (__) — REV B

980429 11:40 KSUKZP



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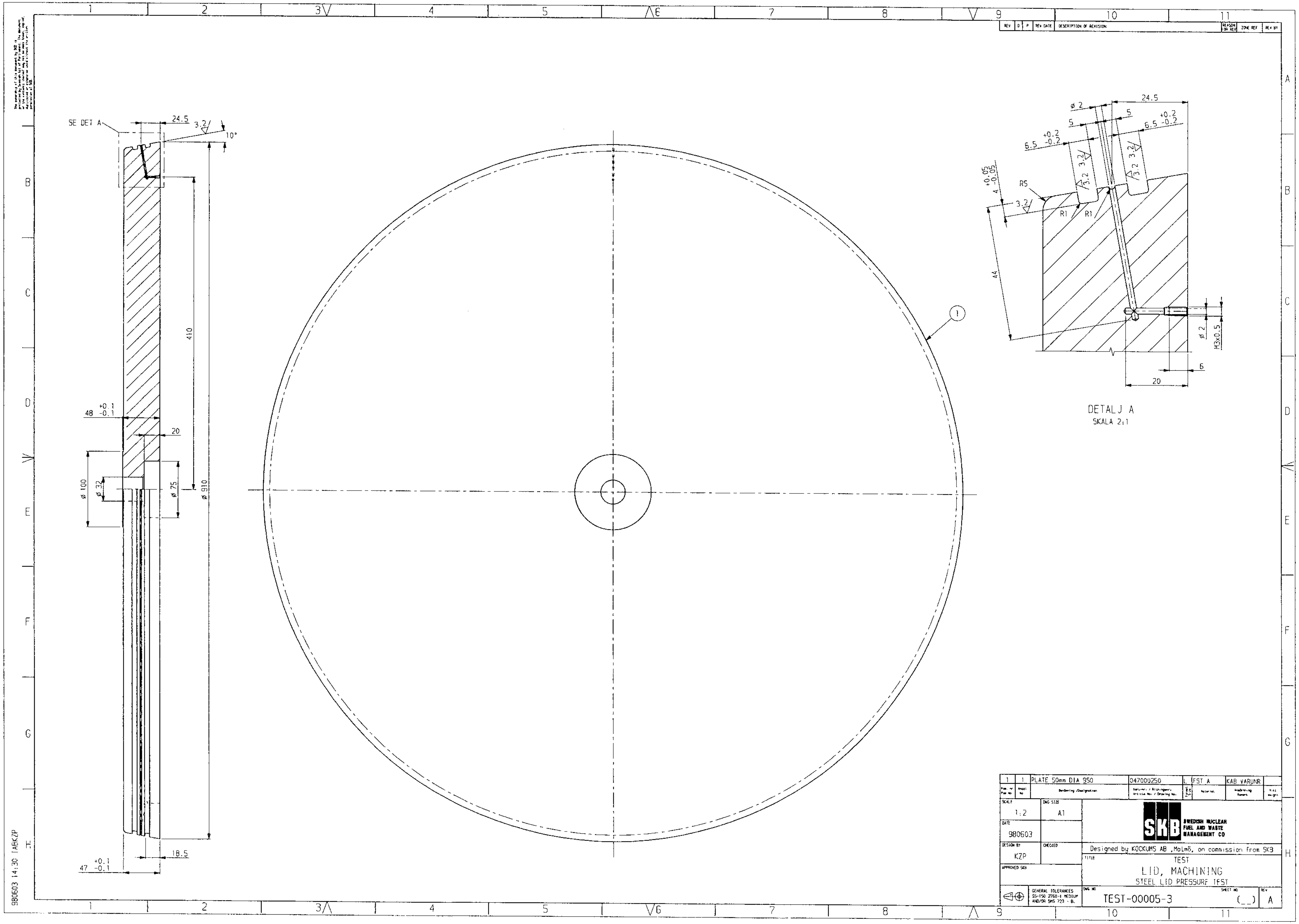
B	X		9810	CO-SKB00002			KZP
C	X		9814	CO-SKB00005			KZP

Pos No	No	Benämning / Designation	Article No / Drawing No		Material	Remark	Weight
12	1	PLATE T=10 200 X 200			SS 2134		
11	1	PLATE T=15 150 X 150			SS 2134		
10	2	FLAT BAR 80 X 15 L=225			SS 1312		
9	1	FLAT BAR 80 X 15 L=530			SS 1312		
8	12	FLAT BAR 80 X 10 L=200			SS 1312		
7	40	FLAT BAR 50 X 10 L=70			SS 1312		
6	4	PLATE T=10 180 X 100			SS 2134		
5	1	ROUND BAR DIA=30 L=140			SS 1312		
4	4	NUT M6M-48	ANS 511337		8.8 OBEH		
3	4	PLATE T=10 280 X 280			SS 2134		
2	4	VKR 160 X 80 X 10			SS 2134		
1	4	VKR 250 X 250 X 10			SS 2134		


SE DET A
24.5
3.2
10°
+0.1
48 -0.1
20
410
ø 100
ø 32
ø 75
ø 910
18.5
+0.1
47 -0.1
1
ø 2
5
+0.2
6.5 -0.2
+0.05
4 -0.05
R5
R1
44
M3x0.5
6
DETALJ A
SKALA 2:1
980603 14:30 TABKZP
1
PLATE 50mm DIA 950
047000250
FST A
KAB VARUNR
SCALE 1:2
DWG SIZE A1
DATE 980603
DESIGN BY KZP
CHECKED
APPROVED SKB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
Designed by KOCKUMS AB ,Malmö, on commission from SKB
TITLE
TEST
LID, MACHINING
STEEL LID PRESSURE TEST
GENERAL TOLERANCES SS-ISO 2768-1 MEDIUM AND/OR SMS 723 - B.
DWG NO TEST-00005-3
SHEET NO (__)
REV A

Projekt Inkapsling – Kapseltillverkning

Revision no	2
Valid from	1998-02-01
Reviewed by	C-GAndersson
Approved by	T Hedman

Overview

Table of contents

Projekt Inkapsling – Kapseltillverkning

List of procedures

Revision no	2
Valid from	1998-02-01
Reviewed by	C-G Andersson
Approved by	T Hedman

17 List of procedures

Procedure	Heading	Remark
KT0501	Requirements for external quality auditing	
KT0601	Techniques for quality analysis	
KT0602	Qualification of manufacturing process	
KT0603	Qualification of supplier/subcontractor (manufacturing)	
KT0604	Qualification of supplier/subcontractor (inspection and metrological confirmation)	
KT0605	Qualification of non-destructive testing methods	x)
KT0701	Final inspection and testing	
KT0702	Packing and transport of canisters and/or canister components	
KT0703	Delivery of canisters and/or canister components, documentation	
KT0704	Requirements on quality plan and manufacturing and inspection plan	
KT0705	Identification of canister components	
KT0801	Control of inspection, measuring and test equipment	x)
KT0802	Maintenance of process equipment	x)
KT0803	Receiving inspection	x)
KT1001	Establishing and control of procedures	
KT1002	Retaining of quality documents and records	
KT1003	Handling of documents regarding canisters from trial manufacture	
KT1004	Establishing and control of technical specifications	
KT1101	Control of nonconformities at SKB	x)
KT1102	Request for concession	
KT1103	Control of nonconformities at supplier	

x) currently being produced

The audit status for procedures can be concluded from the table of contents in the specially set up data register, or in the binder concering procedures.

SKB

**Encapsulation Plant Project –
Canister Manufacturing Technique**

Procedure No KT0705

Identification of Canister Components

Table of Contents

Encapsulation Plant Project –
Canister Manufacturing Technique

Procedure No KT0705

Identification of Canister Components

Revision No 0
Valid from 25 Jan 1998
Reviewed by
Approved by

KT0705 Identification of Canister Components

1 Purpose

The purpose of this procedure, KT0705, is to describe requirements on physical marking of canister components and assembled canisters ordered by SKB, with individual identification numbers.

2 Definition

marking
method of permanently providing canister components and assembled canisters with physical sign of identity

3 Range of application

This procedure applies when permanent marking of canister components and assembled canisters is required by SKB – Canister Manufacturing Technique, unless other is specified.

4 Responsibilities

The supplier or subcontractor shall appoint a management member to monitor the marking activities.

The supplier or subcontractor is responsible for

- ensuring that operators, performing the marking, are well familiar with the equipment to be used,
- renewing the marking of every canister component after operations such as cutting, bending and machining,
- informing the operators using steel stamps about the re-marking requirements,
- recording the performed marking of canister components and assembled canisters in the prescribed manner.

The operator performing marking at the supplier or subcontractor is responsible for

- using only equipment well familiar to the operator,
- using only "low stress stamps",
- ensuring before use that the stamps are undamaged,
- reporting any discrepancy to the supplier's or subcontractor's management,
- handling and maintaining the equipment in accordance with the equipment manufacturer's directions.

Project Manager Canister Manufacturing Technique, PM, is responsible for

- assessing the identification marking needs in co-operation with Canister Design,
- providing suppliers and/or subcontractors with information about marking requirements.

5 Performance of marking

5.1 Marking equipment

Type of steel stamps to be used: "low stress stamps".
Stamp character size: 10 – 15 mm

5.2 Marking

After each operation such as cutting, rolling and machining of the canister components, all items shall be marked.

The finished canister shall be marked with canister number. Components shall be given identification numbers according to attachment 1.

The position of the marking shall be as specified on the applicable SKB drawing.

6 Records

The supplier or subcontractor is responsible for

- assembling the traceability documentation, including the marking records and any discrepancy reports,
- retaining this information in accordance with SKB requirements,
- submitting the information to SKB – Canister Manufacturing Technique.

PM is responsible for

- retaining records about performed marking of canister components and assembled canisters[1, 2].

7 Document control

QA Administration is responsible for document control, including distribution, of this procedure[3].

----

1 Procedure KT1002
2 Procedure KT1003
3 Procedure KT1001

Encapsulation Plant Project – Canister Manufacturing Technique

Procedure No KT0705	Revision No 0
	Valid from 25 Jan 1998
Identification of Canister Components	Reviewed by C-G Andersson
	Approved by T Hedman

Attachment 1: Numbering System

1 Purpose

The purpose of this attachment to procedure KT0705 is to describe a numbering system for the identification and physical marking of canister components and complete, assembled canisters. These ID-numbers of the individual components shall be used during all manufacturing and in all documentation such as orders, material specifications, manufacturing and quality control records, including those issued by suppliers and subcontractors.

2 Principle

Components	*ID numbers*	*Examples*
Copper tubes	T1, T2, T3...	Tube 1 etc
Bottoms for copper tubes	TB1, TB2, TB3...	Tube Bottom 1 etc
Lids for copper tubes	TL1, TL2, TL3...	Tube Lid 1 etc
Inserts	I1, I2, I3...	Insert 1 etc
Lids for inserts	IL1, IL2, IL3...	Insert Lid 1 etc
Cassettes	K1, K2...	Cassette 1 etc
Complete, assembled canisters	C1, C2, C3...	Canister 1 etc

SKB

Encapsulation Plant Project –
Canister Manufacturing Technique

Technical Specification No KTS001

Material for Copper Canisters

Revision No 0
Valid from 1 June 1998
Prepared by [signature]
Reviewed by [signature]
Approved by [signature]

KTS001 Material for Copper Canisters

1 Purpose

The purpose of this technical specification, KTS001, is to define technical requirements and documentation routines for copper ingots, rolled copper plates or copper hot extrusions.

2 Technical requirements

2.1 Material specification

The material for copper canisters shall fulfil the specification in the standard UNS C10100 (Cu-OFE, table 2) or En 133/63:1994 Cu-OF1 (table 3) with the following additional requirements: O < 5 ppm, P 40 – 60 ppm, H < 0,6 ppm, S < 8 ppm and in **rolled plates** or **extrusions** a grain size of 180 – 360 µm. The grain size is measured according to ASTM's comparison method E112-95.

2.2 Chemical composition, grain size, and mechanical properties

Table 1. Requirements and comments concerning chemical composition, grain size, and mechanical properties

Requirements	Specification	Comments
Weldability	O < 5 ppm	Higher levels give a reduced weldability.
Ductility	H < 0,6 ppm	Higher levels give reduced mechanical properties. (Hydrogen embrittlement).
Tensile strength, ductility	S < 8 ppm	Higher levels give reduced mechanical properties caused by non-dissolved sulphur which will be concentrated to grain boundaries.
Creep ductility	P 40 – 60 ppm	A phosphorus content of this order reduces the influence of sulphur impurities, increases creep ductility, increases recrystallisation temperature and has a minor influence on the weldability.
	Grain size 180 – 360 µm (Plates or extrusions)	This grain size gives a resolution at ultrasonic testing comparable to X-ray testing of 50 mm thick copper.
Ductility	Elongation > 40% RT – 100°C (Plates or extrusions)	The canister will be deformed 4% in final repository.
Creep ductility	Elongation at creep-rupture > 10% RT – 100°C (Plates or extrusions)	Same comment as above.

Encapsulation Plant Project – Canister Manufacturing Technique

Technical Specification No KTS001

Revision No	0
Valid from	1 June 1998
Prepared by	C-G Andersson
Reviewed by	L Werme
Approved by	T Hedman

Material for Copper Canisters

Table 2. UNS C10100 composition

Element	Cu	Ag	As	Fe	S	Sb	Se	Te	Pb
	%	ppm[2] →							
	99,99[1]	25	5	10	15	4	3	2	5
		Bi	Cd	Mn	Hg	Ni	O	Sn	Zn
		ppm[2] →							
		1	1	0,5	1	10	5	2	1

Table 3. EN 133/63 Cu-OF1 composition

Element	Cu	Ag	As	Fe	S	Sb	Se	Te	Pb
	(rem.)	ppm →							
		25[2]	5[3]	10[4]	15[2]	4[2]	2[5]	2[6]	5[2]

1 Including Ag
2 Maximum content
3 $\sum$ As + Cd + Cr + Mn + Sb $\leq$ 15 ppm
4 $\sum$ Co + Fe + Ni + Si + Sn + Zn $\leq$ 20 ppm
5 $\sum$ Bi + Se + Te $\leq$ 3 ppm
6 $\sum$ Se + Te $\leq$ 3,0 ppm

2.3 Nominal size and tolerances

Copper ingot

Nominal weight, size and surface condition according to SKB order.

Rolled plate

Nominal length, width and thickness according to SKB order.

Tolerances:

- Thickness +5% / -0 mm
- Width +5 / -0 mm
- Length +5 / -0 mm
- Flatness 5mm

Extruded tube

Nominal length, diameter, wall thickness and tolerances according to SKB order.

3 Inspection and testing of plate or tube

3.1 Soundness

The rolled plate or the extruded tube shall be controlled by 100% ultrasonic testing. Size and shape of reference defect and acceptance criteria shall be as stated in SKB order.

3.2 Mechanical properties and structure

Test pieces for tensile testing (Rp 0,2; Rm; A 50 mm), specimens for hardness test (HRF) and grain size/structure inspection shall be taken from each plate or extruded tube.

Tensile testing shall be performed in the normal manner. Hardness and grain size/structure shall be determined close to the surface and also in the centre of the material. The structure shall be documented by photos at circa 100 x magnification.

4 Documentation

4.1 Certification of copper ingots

The copper ingot manufacturer shall issue a certificate according to EN 10204 3.1.B, stating as a minimum:

- the manufacturer's name and address,
- date of issue,
- order number,
- heat or cast number,
- copper ingot dimensions and weight,
- applicable standard,
- chemical composition,
- result of hydrogen embrittlement test (ASTM B 170), determination of electrical conductivity and density,
- a declaration that the material has been produced in accordance with the company's own current quality system.

4.2 Hot forming process

The hot forming process shall be performed in such a manner that the specified properties of the delivered product are met. The process shall be controlled and documented by the manufacturer of plate or tube to the extent necessary for ensuring reproducibility.

4.3 Certification of processed copper material

The plate or tube manufacturer shall issue a certificate according to EN 10204 3.1.B, stating as a minimum:

- the manufacturer's name and address,
- date of issue,
- SKB order number,
- original heat or cast number,
- lot number and/or number of the rolled plate or extruded tube,
- dimensions and weight of the plate or tube,
- results of ultrasonic testing, tensile and hardness testing, and determination of grain size and structure,
- a declaration that the material has been produced in accordance with the company's own current quality system.

4.4 Submission of documents and information

Before rolling or extrusion, the copper ingot certificate according to 4.1 shall be sent to SKB by mail or telefax for authorization.

The certification according to 4.3 shall be sent to SKB for authorization prior to delivery of the rolled plate or extruded tube.

The supplier shall, without delay, give complete information to SKB on all observations and other circumstances in connection with the production which may influence the design of the copper canister. SKB shall have the right to use this information without any restriction.

5 Document control

QA Administration is responsible for document control, including distribution, of this technical specification[1].

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1 Procedure KT1001

**Encapsulation Plant Project –
Canister Manufacturing Technique**

Technical Specification No KTS011

Revision No 0
Valid from 1 June 1998
Prepared by
Reviewed by
Approved by

Nodular Cast Iron SS 0717 Insert

KTS011 Nodular Cast Iron SS 0717 Insert

1 Purpose

The purpose of this technical specification, KTS011, is to define the technical requirements and documentation for nodular cast iron inserts.

2 Technical requirements

2.1 Material specification

The material specification for nodular cast iron inserts coincides with the requirements in SS 14 07 17- 00, issue 4 1981.

3 Production

3.1 Drawings

Drawings according to applicable SKB order shall be used for the production and inspection of inserts.

3.2 Steel section cassette[1]

The cassette shall be shot blasted and stored under dry conditions to prevent rusting. The shot blasting shall be done as closely in time as possible prior to casting.

3.3 Casting

The melt temperature at the beginning of the casting shall be recorded.

Sample for chemical analysis shall be taken in accordance with normal praxis.

The time from casting to the knocking out shall be recorded.

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1 Specification KTS021

4 Inspection and testing

4.1 Tensile testing and micro structure evaluation

Test pieces for tensile testing shall be taken from cast-on test samples close to the top and bottom of the casting. Normal tensile testing shall be performed. Requirements for separately cast test samples according to SS 14 07 17- 00 shall apply.

Hardness testing (HB) and micro structure evaluation shall also be performed on the test pieces. The structure shall be documented in micrographs at circa 100x magnification.

4.2 Size and shape inspection

The casting shall be measured to check its conformity with the specified size.

For BWR fuel canister prototypes with cassettes made from square sections (VKR) 180 x 180 x 10 mm (outer size x thickness) the straightness of the channels shall be sufficient to permit a 152 x 152 mm square profile template in accordance with applicable SKB drawing to freely move down the entire channel.

For PWR fuel canister prototypes with cassettes sections 250 x 250 x 10 mm the corresponding template size is 224 x 224 mm.

4.3 Ultrasonic testing

The casting shall be tested from the outside with regard to inner defects such as non-metallic inclusions and other inhomogeneities. 100% outside testing shall be performed. A 6 mm diameter flat bottom hole shall be used as the reference defect. Inhomogeneities giving indications equal to or greater than 50% of the reference level shall be recorded. The position and size shall be recorded on sketches.

Operators shall have a documented competence according to ASNT-TC-1A Level 2.

5 Documentation

5.1 Photographic documentation

The production sequence shall be photographically documented when required by SKB. The extent is to be agreed with SKB from case to case.

5.2 Certification

A certificate according to EN 10204 3.1.B shall be issued by the producer stating as a minimum:

- the producer's name and address,
- SKB order number,
- SKB drawing number,
- casting date,
- cast or heat number,
- weight of casting,
- chemical composition,
- results of tensile testing, micro structure evaluation, size and shape inspection, and ultrasonic testing,
- a declaration that the material has been produced in accordance with the company's own current quality system.

5.3 Submission of documents and information

The documentation according to 3.3, 5.1 and 5.2 shall be sent to SKB for authorization prior to delivery.

The supplier shall, without delay, give complete information to SKB on all observations and other circumstances in connection with the production which may influence the design of the insert. SKB shall have the right to use this information without any restriction.

6 Document control

QA Administration is responsible for document control, including distribution, of this technical specification.[1]

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1 Procedure KT1001

Encapsulation Plant Project – Canister Manufacturing Technique

Technical Specification No KTS021

Steel Section Cassette

Revision No 0
Valid from 1 June 1998
Prepared by
Reviewed by
Approved by

KTS021 Steel Section Cassette

1 Purpose

The purpose of this technical specification, KTS021, is to define the technical requirements and documentation for the manufacture of steel section cassettes intended for cast canister inserts.

2 Technical requirements

2.1 Material specification for square sections

The material specification for VKR[1] (RHS[2]) square hollow sections coincides with the requirements in SS 14 21 34-04, issue 4 1993, concerning chemical composition and mechanical properties (ReL, Rm, A5). Test pieces for determination of lower yield strength, tensile strength and elongation according to SS 11 21 10 shall be used.

For BWR fuel canisters 180 x 180 x 10 mm (outer size [D] x thickness [t]) VKR square section size applies, and for PWR fuel canisters the corresponding size is 250 x 250 x 10 mm.

Size and shape tolerances, based on SS 21 28 20 and SS 21 28 30:
- D: ± 1% of D
- t: – 6% of t
- squareness: 90° ± 1°
- flatness deviation: ≤ 1% of D (across section, inwards or outwards)
- skewness: max 2 mm + 0,5 mm/m section length
- outer corner radius: max 3 t
- length: +10 – 0 mm
- straightness: 0,20% of total length

Seamless sections as well as welded sections can be used. In the latter case the weld bead shall be flush against the section inner wall, if necessary machined.

2.2 Material specification for plates and flat bars

The material specification for steel plates and flat bars coincides with the requirements in SS 14 13 12, issue 11 1990.

Plate and bar sizes are specified on applicable SKB drawings.

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1 Hot finished square structural hollow sections (Varmbearbetade konstruktionsrör)
2 Rectangular hollow sections

2.3 Material specification for tubes

The material specification for steel tubes coincides with the requirements in SS 14 21 72, issue 11 1990.

The tube size is specified on the applicable SKB drawing.

3 Production

3.1 Drawings

Drawings according to applicable SKB order shall be used for the manufacture of cassettes.

3.2 Manufacture of steel section cassette

The cassette shall be assembled by welding. The selection of welding method is at the discretion of the manufacturer but shall follow a welding procedure specification (WPS), issued by the manufacturer. Precautions shall be taken to prevent deformation of the sections as well as burning-through during the welding operation.

4 Inspection and testing

4.1 Size and shape inspection

The completed manufactured cassette shall be measured to check its conformity with the specified size and shape. For prototype cassettes made from square sections (VKR) 180 x 180 x 10 mm (outer size x thickness) the straightness of the channels shall be sufficient to permit a 156 x 156 mm square profile template, manufactured according to applicable SKB drawing, to freely move down the entire channel.

For cassettes made from 250 x 250 x 10 mm sections the corresponding square profile template shall be 226 x 226 mm.

4.2 Inspection of welds

The complete, welded cassette shall be visually inspected for welding defects, and the welded bottom ends of the sections shall be penetrant tested. Cracks and incomplete welds at the bottom ends are not permitted. Any defects of such a type shall be repaired by welding and subsequently inspected by the manufacturer.

Encapsulation Plant Project – Canister Manufacturing Technique

Technical Specification No KTS021	Revision No	0
	Valid from	1 June 1998
	Prepared by	C-G Andersson
Steel Section Cassette	Reviewed by	L Werme
	Approved by	T Hedman

5 Documentation

5.1 Steel section certificates

The steel section producer shall issue a certificate according to EN 10204 2.2, or higher, stating, as a minimum:

- the steel section producer's name and address,
- reference to applicable material/product standard,
- result of chemical analysis and mechanical testing of material according to clause 2.

5.2 Photographic documentation

The cassette manufacture shall be photographically documented when required by SKB. The extent is to be agreed with SKB from case to case.

5.3 Other documentation

The cassette manufacturer shall issue a report indicating

- weight of cassette,
- result of size and straightness inspection,
- result of visual and penetrant inspection of welds.

5.4 Submission of documents and information

The documentation mentioned in 5.1, 5.2 and 5.3 shall be submitted to SKB by the party receiving the SKB order (foundry or cassette manufacturer).

The supplier shall also, without delay, give complete information to SKB and to the foundry concerned on all observations and other circumstances in connection with the production which may influence the design of the cassette. SKB shall have the right to use this information without any restriction.

6 Document control

QA Administration is responsible for document control, including distribution, of this technical specification[1].

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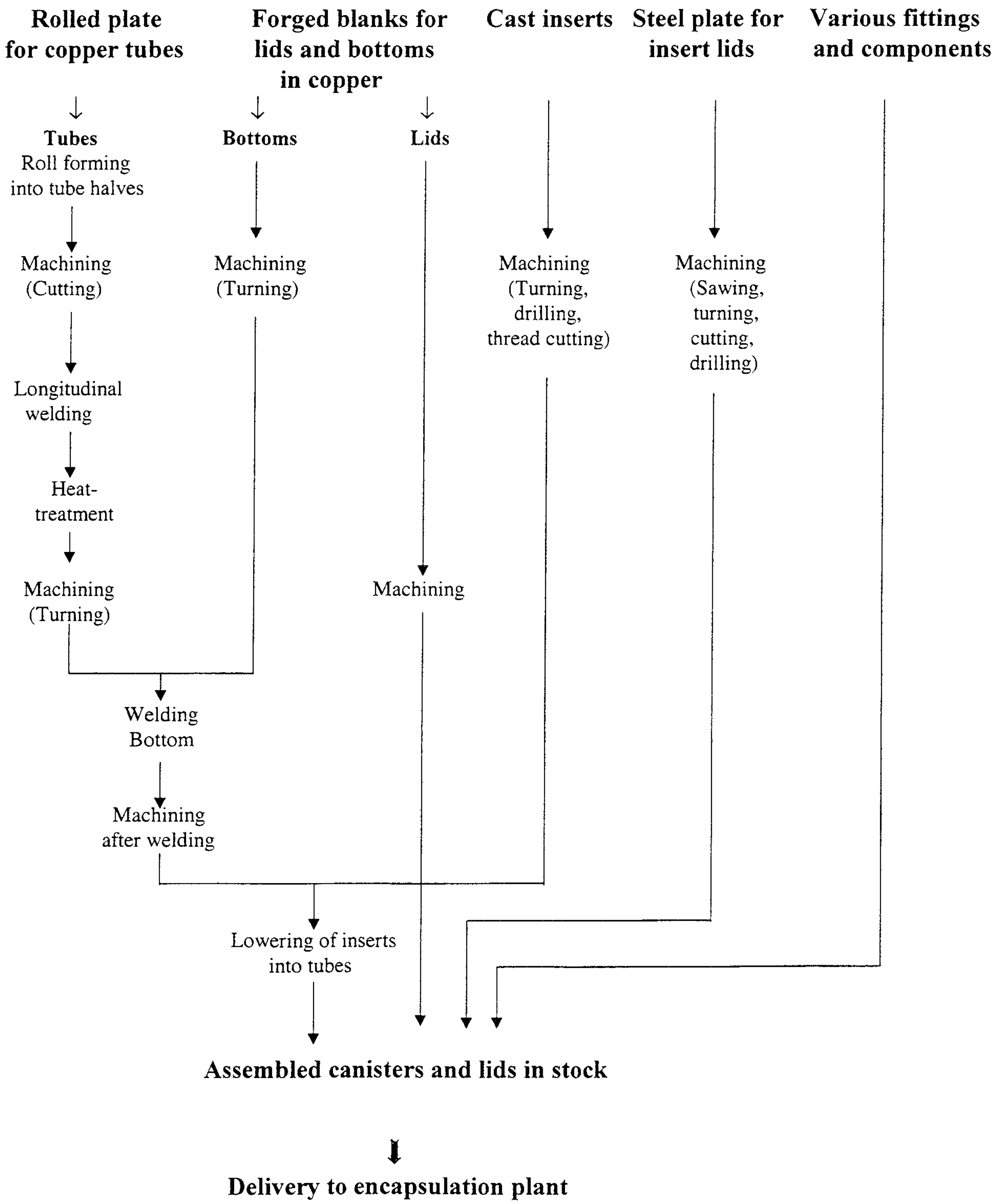
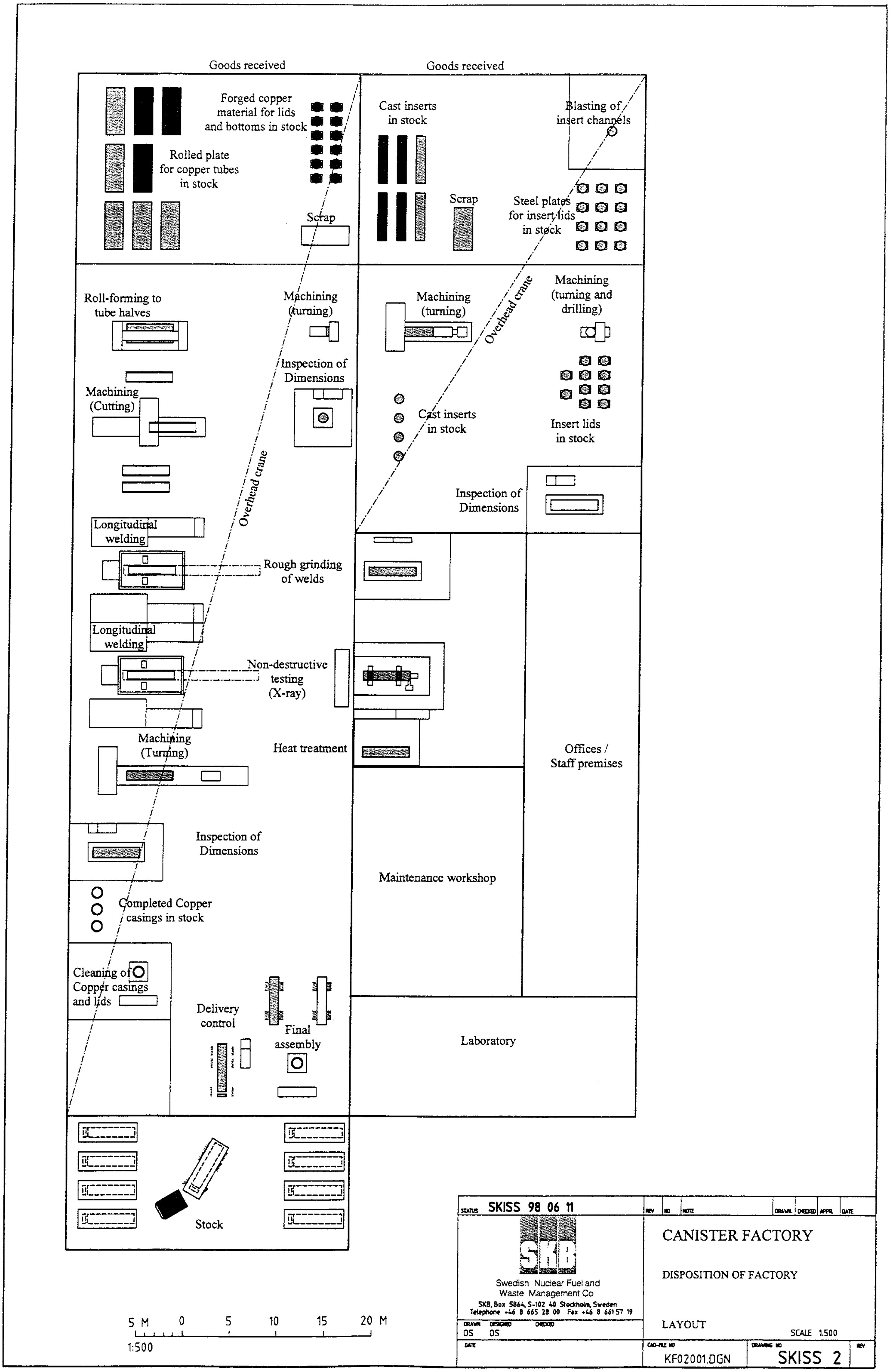
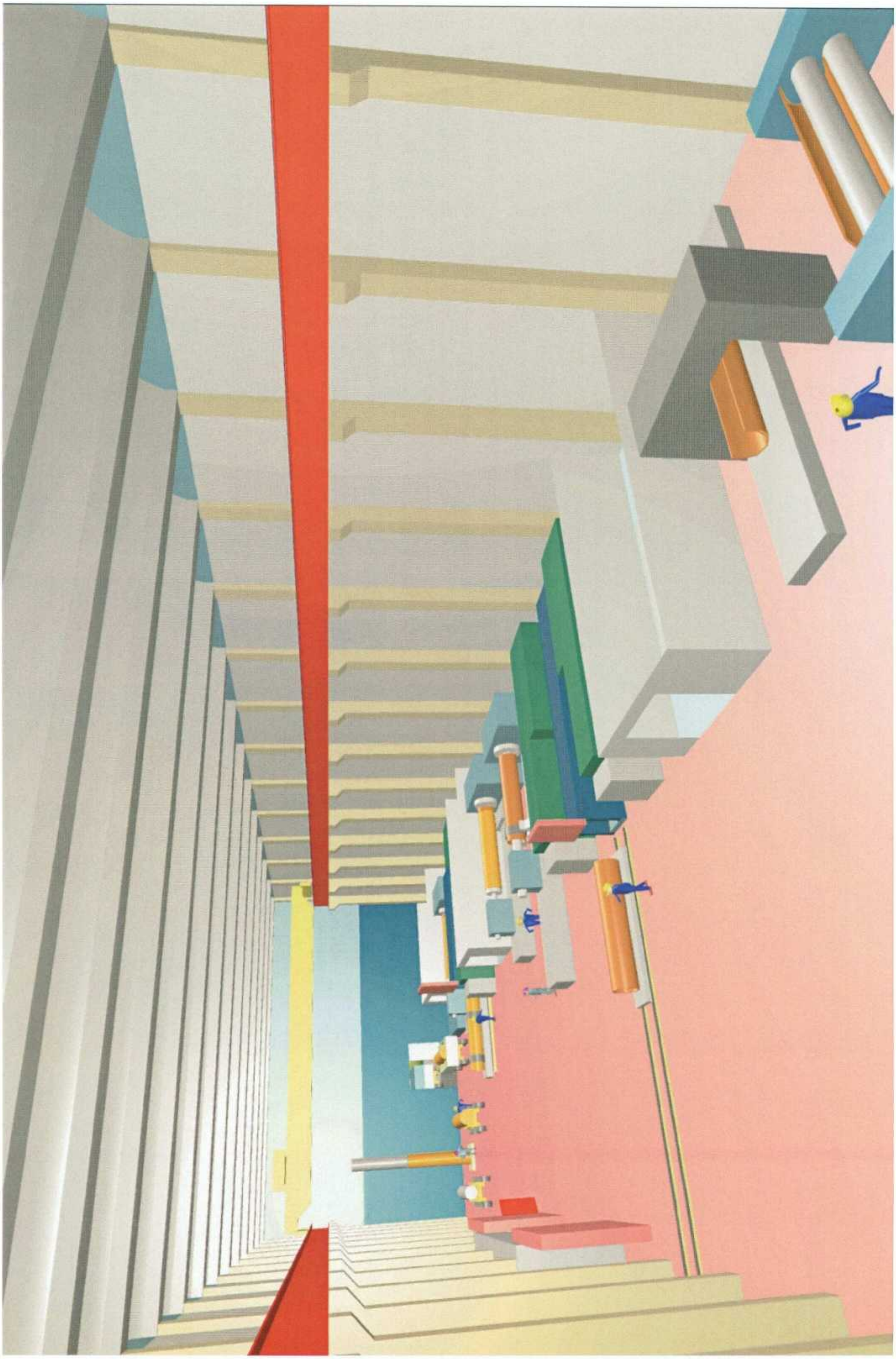
1 Procedure KT1001

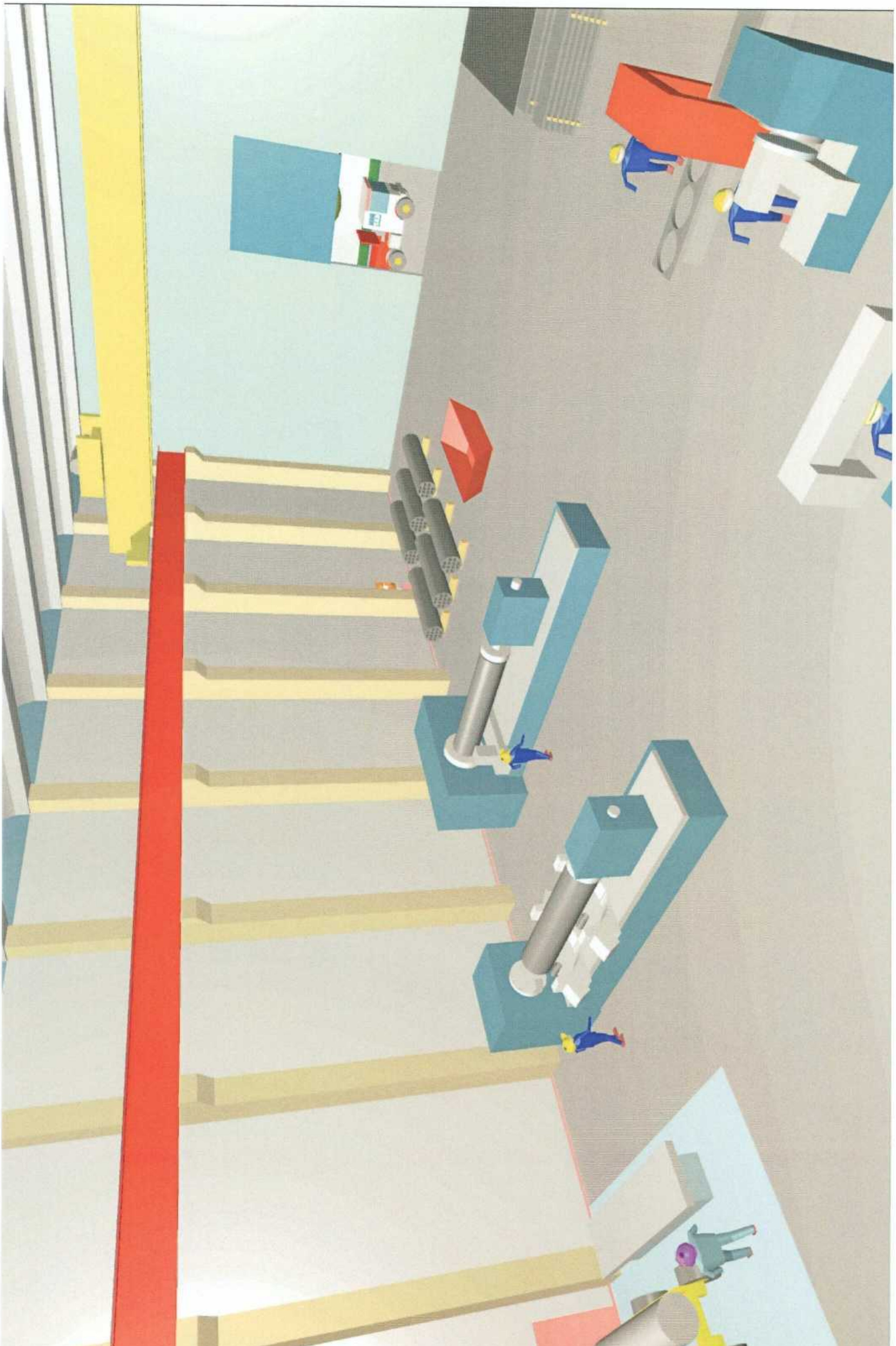
THE CANISTER FACTORY
OVERVIEW-FLOWCHART

Incoming material from subcontractors




Goods received
Goods received
Forged copper material for lids and bottoms in stock
Rolled plate for copper tubes in stock
Scrap
Cast inserts in stock
Blasting of insert channels
Scrap
Steel plates for insert lids in stock
Roll-forming to tube halves
Machining (turning)
Machining (turning)
Overhead crane
Machining (turning and drilling)
Inspection of Dimensions
Machining (Cutting)
Cast inserts in stock
Insert lids in stock
Overhead crane
Inspection of Dimensions
Longitudinal welding
Rough grinding of welds
Longitudinal welding
Non-destructive testing (X-ray)
Machining (Turning)
Heat treatment
Offices / Staff premises
Inspection of Dimensions
Maintenance workshop
Completed Copper casings in stock
Cleaning of Copper casings and lids
Delivery control
Final assembly
Laboratory
Stock
5 M 0 5 10 15 20 M
1:500
STATUS SKISS 98 06 11
REV NO NOTE DRAWN CHECKED APPR DATE
SKB
Swedish Nuclear Fuel and Waste Management Co
SKB, Box 5864, S-102 40 Stockholm, Sweden
Telephone +46 8 665 28 00 Fax +46 8 661 57 19
CANISTER FACTORY
DISPOSITION OF FACTORY
LAYOUT
SCALE 1:500
DRAWN DESIGNED CHECKED
OS OS
DATE
CAD-FILE NO
KF02001.DGN
DRAWING NO
SKISS 2
REV





List of SKB reports

Annual Reports

1977-78
TR 121
KBS Technical Reports 1 – 120
Summaries
Stockholm, May 1979

1979
TR 79-28
The KBS Annual Report 1979
KBS Technical Reports 79-01 – 79-27
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Stockholm, March 1980

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The KBS Annual Report 1980
KBS Technical Reports 80-01 – 80-25
Summaries
Stockholm, March 1981

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Stockholm, April 1982

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Summaries
Stockholm, July 1983

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The KBS Annual Report 1983
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Stockholm, June 1984

1984
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Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01 – 84-19)
Stockholm, June 1985

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Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01 – 85-19)
Stockholm, May 1986

1986
TR 86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

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TR 87-33
SKB Annual Report 1987
Including Summaries of Technical Reports Issued during 1987
Stockholm, May 1988

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Stockholm, May 1989

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Including Summaries of Technical Reports Issued during 1989
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SKB Annual Report 1990
Including Summaries of Technical Reports Issued during 1990
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SKB Annual Report 1991
Including Summaries of Technical Reports Issued during 1991
Stockholm, April 1992

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SKB Annual Report 1992
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SKB Annual Report 1993
Including Summaries of Technical Reports Issued during 1993
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SKB Annual Report 1994
Including Summaries of Technical Reports Issued during 1994
Stockholm, May 1995

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TR 95-37
SKB Annual Report 1995
Including Summaries of Technical Reports Issued during 1995
Stockholm, May 1996

1996
TR 96-25
SKB Annual Report 1996
Including Summaries of Technical Reports Issued during 1996
Stockholm, May 1997

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TR 98-01
Global thermo-mechanical effects from a KBS-3 type repository. Summary report
Eva Hakami, Stig-Olof Olofsson, Hossein Hakami, Jan Israelsson
Itasca Geomekanik AB, Stockholm, Sweden
April 1998

TR 98-02
Parameters of importance to determine during geoscientific site investigation
Johan Andersson[1], Karl-Erik Almén[2],
Lars O Ericsson[3], Anders Fredriksson[4],
Fred Karlsson[3], Roy Stanfors[5], Anders Ström[3]
[1] QuantiSci AB
[2] KEA GEO-Konsult AB
[3] SKB
[4] ADG Grundteknik KB
[5] Roy Stanfors Consulting AB
June 1998

TR 98-03
Summary of hydrochemical conditions at Aberg, Beberg and Ceberg
Marcus Laaksoharju, Iona Gurban,
Christina Skårman
Intera KB
May 1998

TR 98-04
Maqarin Natural Analogue Study: Phase III
J A T Smellie (ed.)
Conterra AB
September 1998

TR 98-05
The Very Deep Hole Concept – Geoscientific appraisal of conditions at great depth
C Juhlin[1], T Wallroth[2], J Smellie[3], T Eliasson[4],
C Ljunggren[5], B Leijon[3], J Beswick[6]
[1] Christopher Juhlin Consulting
[2] Bergab Consulting Geologists
[3] Conterra AB
[4] Geological Survey of Sweden
[5] Vattenfall Hydropower AB
[6] EDECO Petroleum Services Ltd.
June 1998

TR 98-06
Indications of uranium transport around the reactor zone at Bagombe (Oklo)
I Gurban[1], M Laaksoharju[1], E Ledoux[2], B Made[2],
A L Salignac[2],
[1] Intera KB, Stockholm, Sweden
[2] Ecole des Mines, Paris, France
August 1998

TR 98-07
PLAN 98 – Costs for management of the radioactive waste from nuclear power production
Swedish Nuclear Fuel and Waste Management Co
June 1998

TR 98-08
Design premises for canister for spent nuclear fuel
Lars Werme
Svensk Kärnbränslehantering AB
September 1998