SKB

TECHNICAL REPORT

91-38

Production methods and costs of oxygen free copper canisters for nuclear waste disposal

Hannu Rajainmäki, Mikko Nieminen, Lenni Laakso

Outokumpu Poricopper Oy, Finland

June 1991

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

BOX 5864 S-102 48 STOCKHOLM

TEL 08-665 28 00 TELEX 13108 SKB S

TELEFAX 08-661 57 19

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Hannu Rajainmäki, Mikko Nieminen, Lenni Laakso

Outokumpu Poricopper Oy, Finland

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Information on SKB technical reports from 1977-1978 (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) and 1990 (TR 90-46) is available through SKB.

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Hannu Rajainmäki Outokumpu Poricopper Oy
Mikko Nieminen Outokumpu Poricopper Oy
Lenni Laakso Outokumpu Poricopper Oy

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The fabrication technology and costs of various manufacturing alternatives to make large copper canisters for spent fuel repository are discussed. The capsule design is based on the TVO's new advanced cold process concept where a steel canister is surrounded by the oxygen free copper canister. This study shows that already at present there exist several possible manufacturing routes, which result in consistently high quality canisters. Hot rolling, bending and EB-welding the seam is the best way to assure the small grain size which is preferable for the best inspectability of the final EB-welded seam of the lid. The same route turns out also to be the most economical.

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1 INTRODUCTION

In Finland and Sweden the spent nuclear fuel has been planned to be encapsulated into canisters and deposited into the bedrock 500 m below the earth surface.

Oxygen free copper is being considered as the corrosion resistant material for these canisters. The requirements on the quality and the internal structure of these large and thick wall canisters are high. The present survey addresses the alternative manufacturing techniques and the cost of producing large copper canisters.

The main function of the nuclear waste canister is to keep the radioactive waste confined for a sufficiently long time in order to avoid the risk on the biosphere /1/. The most important criterion for the canister is the corrosion resistance in the repository. The minimum time for the canister to withstand is 1000 years and the design value is 10 000 years minimum.

There is a pressure of 15 MPa (maximum) directed to the canister and thus the copper canister is supported by a steel jacket inside in the TVO's current designs. There are two alternate models which differ in the jacket thicknesses, as seen in Fig. 1. The design of the canisters has been described in detail by Salo and Raiko /2/. In case 1 the inner steel jacket is 55 mm thick surrounded by a 60 mm thick copper jacket. In case 2 they both have a thickness of 50 mm. The weigths of the copper parts in the two cases are given in Table 1. The gap between the jackets is 1 mm maximum in order to minimize the strain in the copper canister below 1 %. The outer diameters of the copper canisters in case 1 and 2 are 802 mm and 822 mm, respectively. The flat copper ends have the same minimum wall thickness as the cylindrical parts.

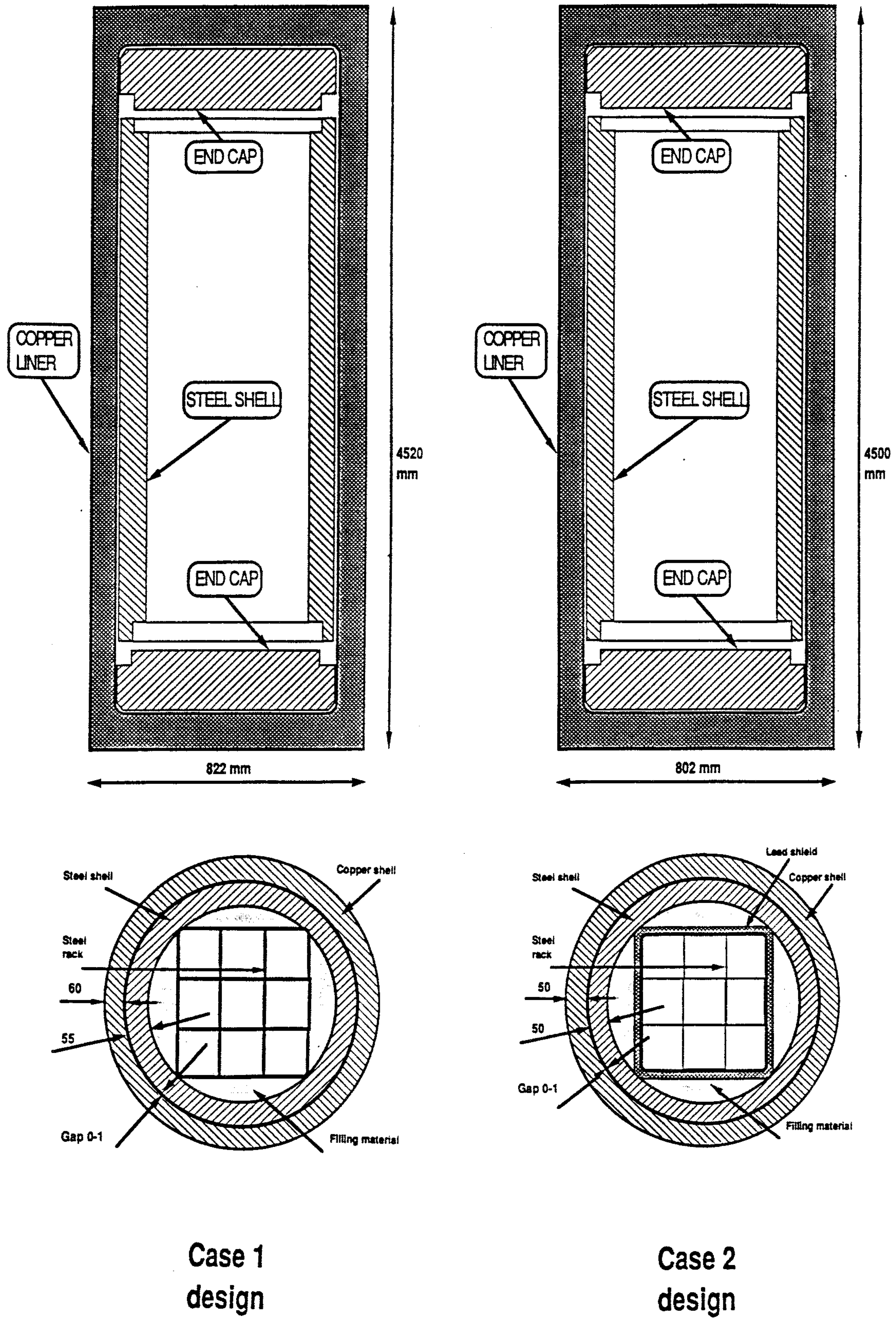


Fig. 1. Schematic illustrations of canister designs, case 1 and case 2.

Table 1. Weigths (kg) of copper parts in the canisters according to case 1 (60 mm wall) and case 2 (50 mm wall).

	Case 1	Case 2
Body as a tube	5650	4670
Lids (2)	570	450
Root support	70	70
Total	6290	5190

In order to maximize the corrosion resistance of copper the structure should have a homogenous grain structure without any disruptions. Preferably the only slight discontinuity is the weld seam of the lid. The position of the weld seam has been chosen so that there is only a moderate stress concentration. The welding of the lid shall be done by electron beam (EB) welding, which gives the best weld seam for the thick sections of copper. The EB-weldability of oxygen free copper has been observed to be the best of the copper grades. Thus oxygen free copper was selected to be the copper grade used for the canisters.

2 MATERIAL REQUIREMENTS

The most important property of the outer canister is corrosion resistance. The corrosion rate of copper is known to be very slow and copper has thus been chosen as the outer canister material. The most important area from the corrosion point of view is the weld seam because it is an inhomogeneity. However, present level of electron beam welding and inspection techniques can guarantee the high quality of the weld seam.

The copper canister contains at least one seam (if HIP technique is excluded), namely the final closure of the lid. This final closure must be done in the hot cell condition since the capsule contains then the fuel elements. The best and most reliable welding method (at present) for thick copper sections is electron beam welding. It is also an advantage that the EB-welded seam can be repaired by another EB-welding in case of improper seam quality. The seam quality can be inspected in the hot cell condition by the ultrasonic inspection technique. This method is most sensitive when the grain size of the material to be inspected is small. Oxygen free copper (C10200) has been found to be the best copper grade to be EB-welded. The oxygen containing and deoxidized grades result in porosity in the weld seam /3/.

The mechanical load of the Cu/steel canister is mainly taken by the steel part. Thus no special requirements on the strength of the copper part are needed. The only criteria are that the canister must withstand the handling and the external pressure of 15 MPa (maximum) caused by the swelling of the surrounding bentonite clay. The 0.2 % proof stress of the hot worked oxygen free copper is around 50 MPa and thus it is sufficiently high.

Copper can easily be both hot worked and cold worked and the desired shape is achieved normally without problems. The manufacturer's workshop has informed that machinability of copper is sufficient to obtain the required -0/+1 mm tolerances of the inner diameter of the canister.

The availability of copper is excellent. The consumption of oxygen free copper for the Finnish and Swedish nuclear waste canisters represents about 1 % of the annual oxygen free copper production in the world during the estimated production period of 10 years.

The price of copper has increased during the past 40 years (Fig. 2), but the price has followed the inflation rate (excluding statistical fluctuations). The present LME price of A-grade copper cathodes is 9.90 FIM/kg (18.4.1991), which has been used in the canister production cost estimates.

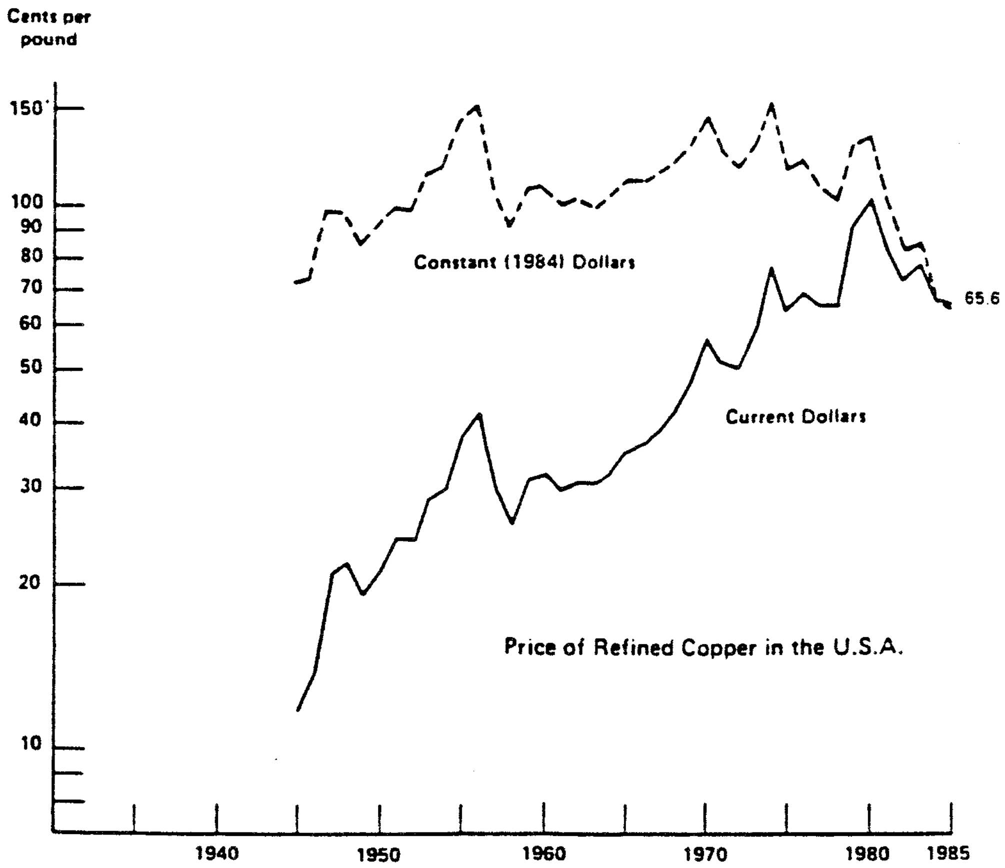


Fig. 2. The real price of copper (dashed line) /4/.

3 BASIC PRODUCTION METHODS

3.1 Casting

Oxygen free copper is produced by melting and casting the copper cathodes in a reducing atmosphere. The highest purity (A-grade) copper cathodes are used as the raw material. The reduction of oxygen from the melt can be done either by carbon or vacuum. Both methods result in a low oxygen content. The casting can be either continuous or semicontinuous which both have their advantages.

The maximum dimensions needed to be cast for the manufacturing of the nuclear waste canisters are 850 mm (diam) for the billets to be hot extruded and 250 x 1200 mm for the cakes to be hot rolled. The maximum length is 2600 mm and the maximum weight is 11.5 tons.

Outokumpu Poricopper Oy (Finland) has an oxygen free copper casting line (Fig. 3), which is capable of producing the ingots for the canisters.

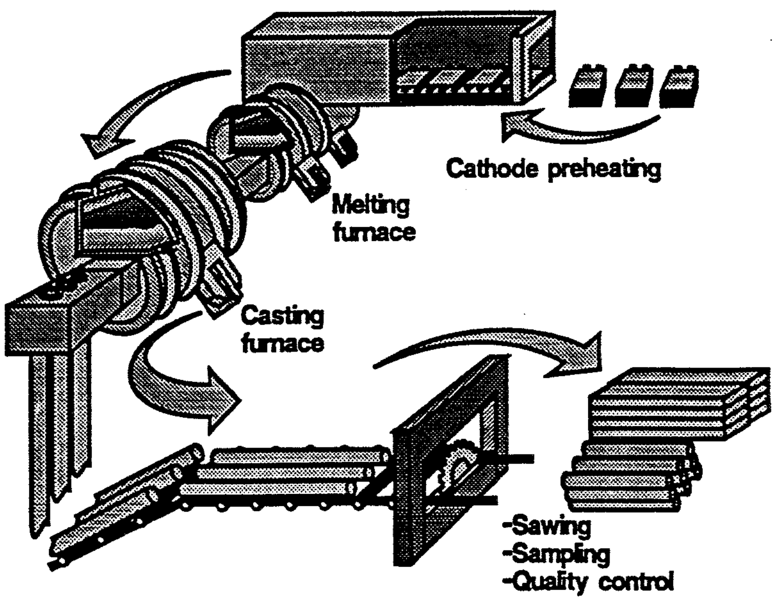


Fig. 3. The oxygen free copper casting line.

The line has a semicontinuous 10 m casting unit which can cast ingots up to 15 tons. The other dimensions can be obtained after some modifications. The casting line contains also a preheating unit in order to remove moisture and impurities from the surfaces of the cathodes. The preheating unit and carbon used for the oxygen reduction from the melt result in a very low oxygen content of 1 - 3 ppm. The oxygen free copper capacity of the casting line of Outokumpu is much higher than the amount of oxygen free copper needed for the Finnish and Swedish nuclear waste canisters (100 - 300 canisters per annum).

3.2 Working

The 800 mm diameter canisters are outside the hot extrusion range of all existing presses except the world's biggest presses of Cooper Industries in Houston, USA (Cameron Forged Products Division) and Livingston, Scotland. The 35 000-ton press extrudes pipe up to 1219 mm in diameter and up to 177 mm in wall thickness. Lengths can vary from 3 to 13 metres. The maximum billet weight is 18 tons /5/.

The 1600 mm diameter canister may also be within the range of extrusion. The largest tube manufactured by extrusion in the USA can have diameter up to 1676 mm /6/. Another possible working method is hot rolling and bending to tube and subsequent EB-welding. Extrusion is preferred, however, because the longitudinal seam is avoided.

Hot working is necessary in order to have the large cast grains replaced by smaller recrystallized grains. The grain size is a crucial factor in the ultrasonic testing of the welds. For easy ultrasonic inspection, the grain size of the base material should be small. This limitation has recently been overcome by the development of computer-driven ultrasonic imaging techniques /6/.

3.2.1 Extrusion methods

Although there seems to be no possibility of choosing between different extrusion methods the basic methods will be briefly reviewed. In direct or forward extrusion the stem and the extruded product move in the same direction and in the indirect or backward extrusion the stem and product move in opposite directions (Fig. 4).

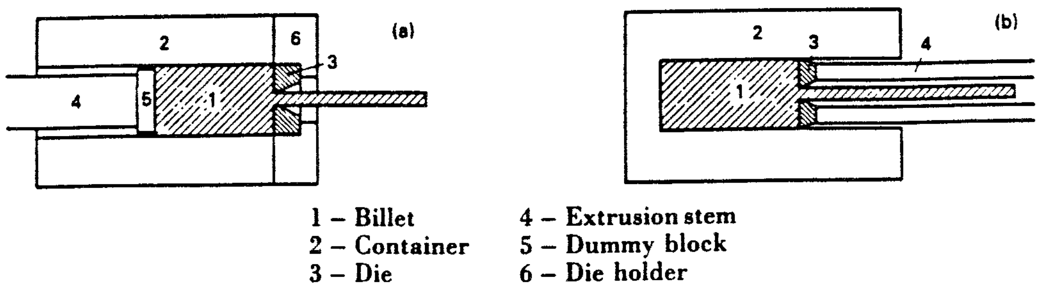


Fig. 4. Direct extrusion (a) and indirect extrusion (b) /7/.

A potential method for producing large diameter tubes is the Raflo process, Fig. 5.

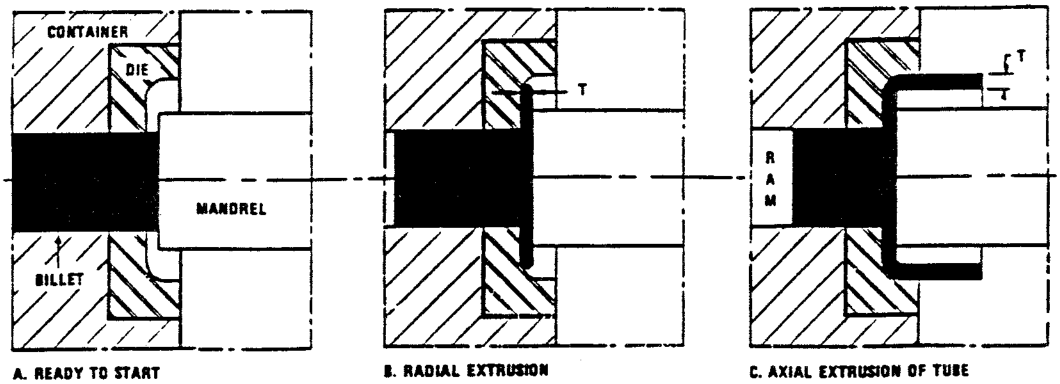


Fig. 5. Schematic operation sequence of the Raflo process /8/.

The Raflo process has advantages over conventional methods such as smaller billet diameter and smaller sufficient press capacity. One limitation is that the mandrel must be longer than the extruded tube. Production presses using this method have not been built. This is unfortunate because the method automatically produces tubes with one end closed.

The Cameron process employs two vertical presses, a 14 000 ton blocking press and 35 000 ton extrusion press. The billet is pierced in the blocking press, Fig. 6.

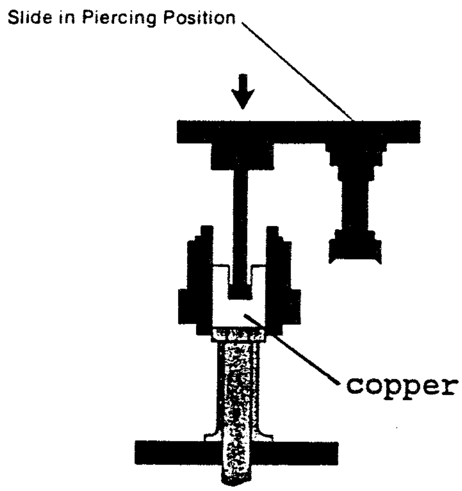


Fig. 6. Cameron's piercing operation /5/.

If the piercing is not completed through the block, then one end remains closed. The shell is then moved to the second press for extrusion. Fig. 7 shows the extrusion in progress.

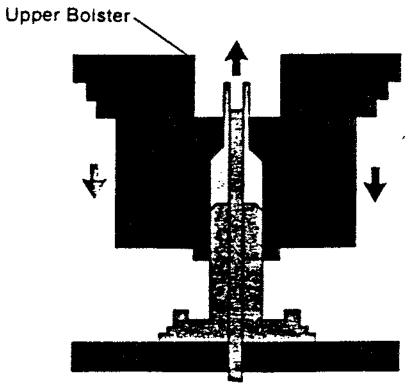


Fig. 7. Direct tube extrusion /5/.

The process in Houston is an example of direct extrusion. The process in Livingston is indirect, however. This version is shown in Fig. 8.

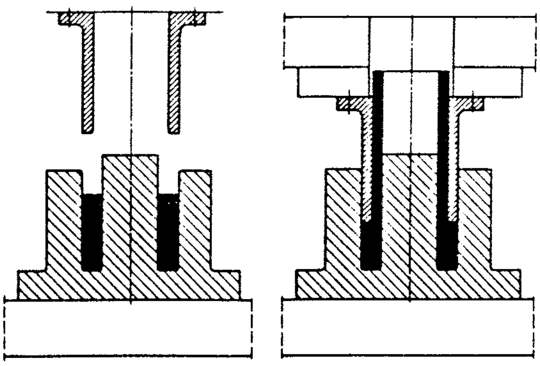


Fig. 8. Indirect extrusion of tube /8/.

3.2.2 Rolling

The principle of rolling is shown in Fig. 9. Hot rolling of copper is done at temperatures of 650 - 900 °C. Several passes through the rolling stand are needed to obtain the desired thickness. The coarse cast grain structure is effectively broken and a finer grain size is obtained. Since this is a hot working operation the copper is in soft condition after rolling. Water cooling can be used to keep the grain size small.

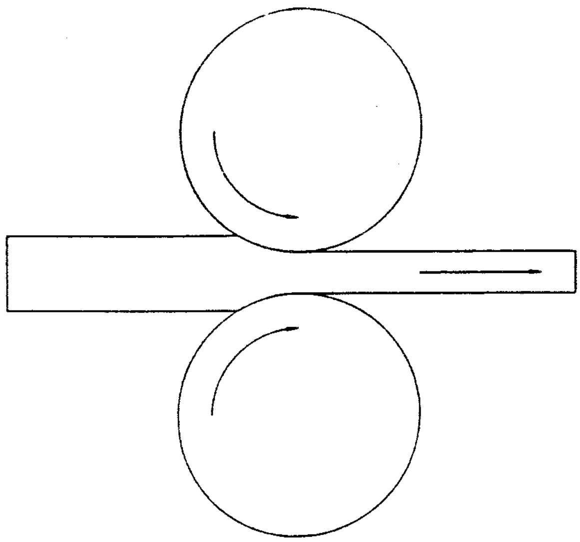


Fig. 9. The principle of rolling.

In contrast to extrusion, hot rolling can be done in Finland. The plants capable of rolling the width required are normally producing steel, however, and consequently there are additional costs associated with the loss of production, when furnace temperatures are changed and so on. This means that hot rolling in a steel mill is much more expensive than in a copper mill. It is to be noted that the nearest copper mill capable of rolling sufficiently wide plate is the Krasnyi Vyboržets plant in Leningrad. It is clear that canister production involving hot rolling in a copper mill is the most favourable production route from the economical point of view.

Hot rolling with bending and EB-welding, involves the longitudinal weld seam which can be avoided with extrusion. Also, the longitudinal seam requires edge preparation before welding.

3.3 Machining

The machinability of oxygen free copper is characterized by long chips and therefore it is not the best possible. Good results can be achieved by using special tool constructions /9/. For standard tools there are special machinable grades of copper that contain tellurium or sulphur additions to improve machinability. When such grades are not used it is desirable to keep the machining at a minimum. This is also important in order to minimize material losses.

3.4 Welding

Electron beam welding is a feasible method to join thick materials (Fig. 14). A beam of high-energy electrons is focused into the welded seam where electrons loose their energy and heat the seam. The heating causes proper joining of the sections. The penetration and the depth of the weld depends on the power of the electron beam. The welding must be performed in vacuum and the sections to be welded together must be machined.

The critical stages in the EB-welding are the beginning and the end, where defects may be formed. However, often the welding can be arranged so that defects do not appear in the welded material. A backing of the weld seam, i.e. a root support (Fig. 10), is required to guarantee full penetration in the copper without penetrating the steel.

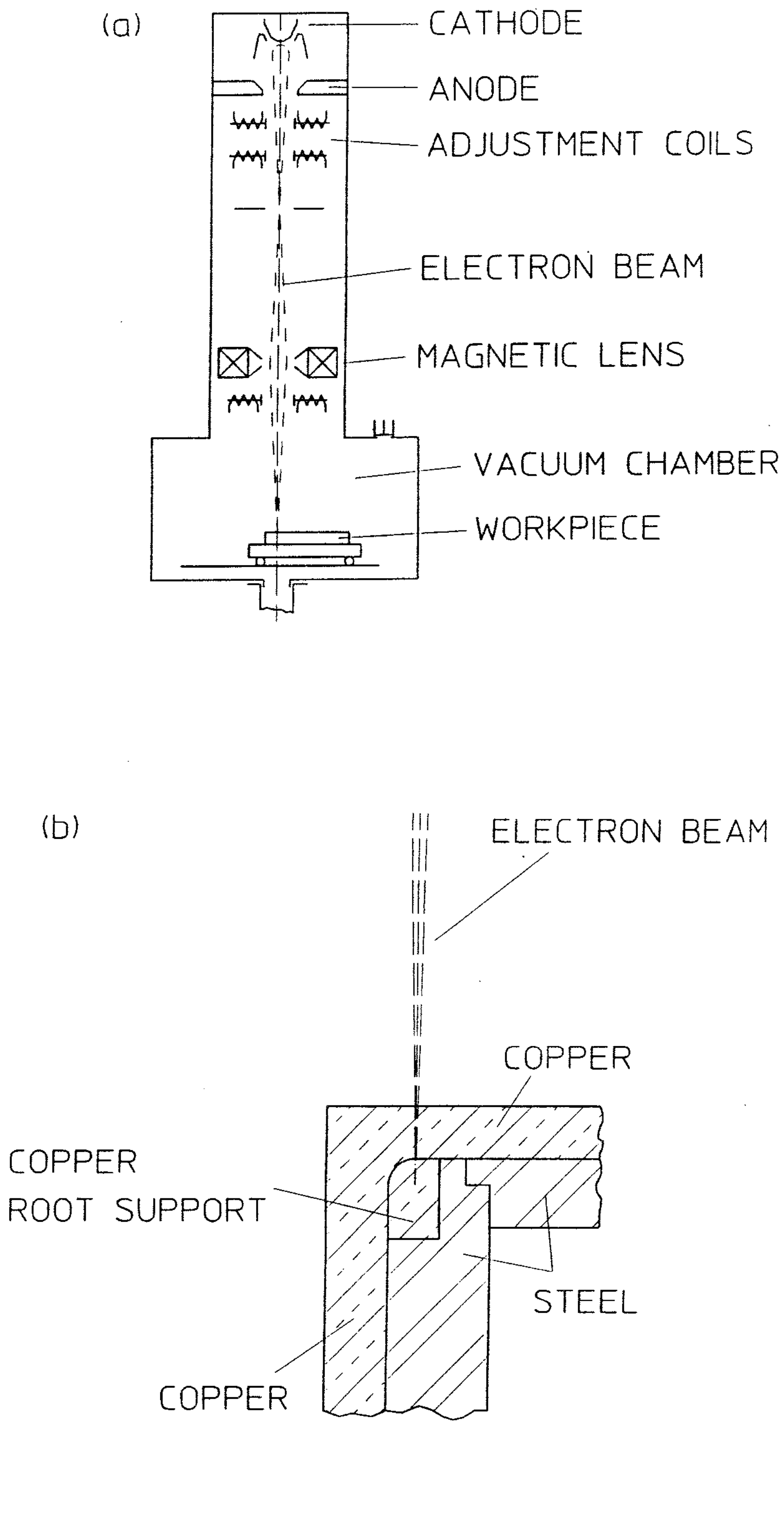


Fig. 10. (a) Electron beam welding equipment /10/, (b) weld seam and root support. Note that the beam may also be horizontal.

The strength of the electron beam welds at elevated temperatures have recently been investigated /11/. Loss of ductility was observed in the welds at high temperatures. However, this is not serious concerning the canister conditions since the maximum temperature is 100 °C.

3.5 Other alternatives

Hot isostatic pressing has been proposed for use as an encapsulation process by the Swedish Nuclear Fuel and Waste Management Co (SKB). In this process heat and isostatic pressure are applied to compact and densify a structure. This method allows the use of oxygen free copper powder as a filling material. The process converts the copper powder, through diffusion and sintering of the particles, into a solid mass of copper. The powder, tube, fuel elements and end pieces are bonded into a seamless integral monolith. Hot isostatic pressing eliminates the need to weld ends on the canister. The joints are formed by diffusion bonding. The size of the canister is a problem, however. There is currently no HIP press in the world long enough to process a full-length canister /6/.

Roll extrusion is another alternative. This process is more commonly known as tube spinning. Other names for this process are shear forming, flow turning, spin forging, rotary extrusion, flow forming, hydrospinning, rotoforming and floturning. Tube spinning is used to reduce the wall thickness and increase the length of tubes without changing their inside diameters.

The spinning can be done hot or cold. There are two different techniques, backward and forward. Spinning can also be done internally. These processes are shown in Fig. 11.

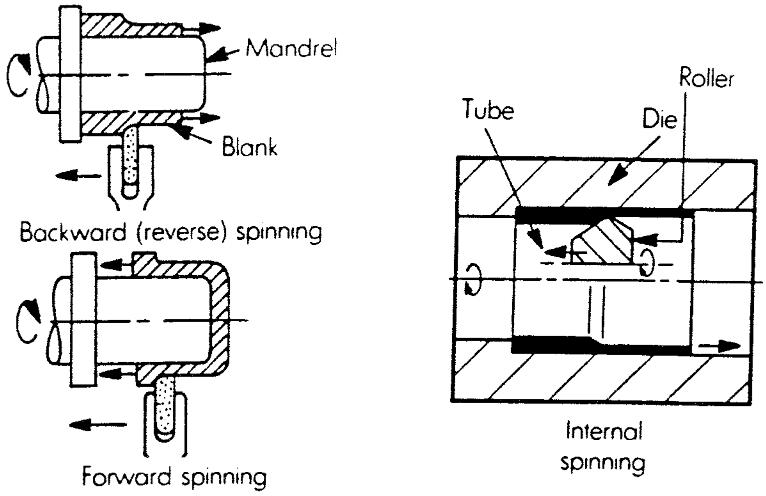
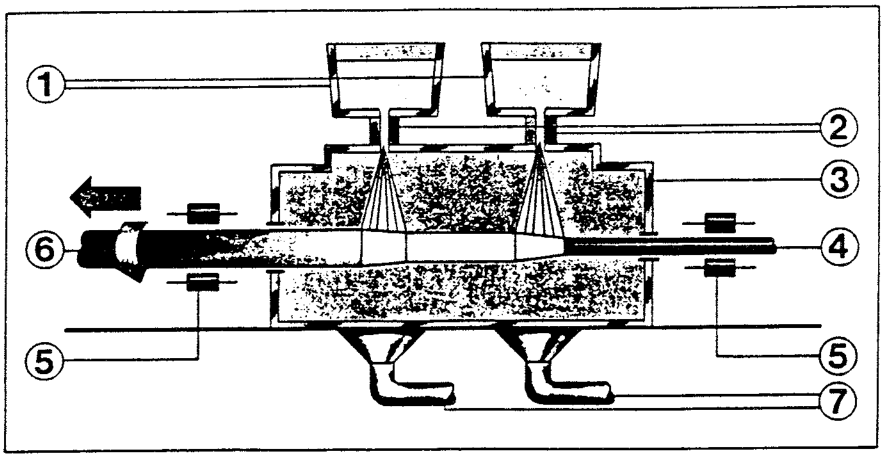


Fig. 11. Types of tube spinning processes /12/.

The method has been used to produce very thin wall large-diameter tubing such as rocket cases. Estimates of the suitability and costs of this method are not presently available and the applicability of the process needs further study.

Centrifugal casting could be a promising production method with its advantages of metallurgical cleanliness and homogeneous microstructure. Unfortunately the method is not suitable for OF copper if performed in air. Centrifugal casting in vacuum is not yet developed to mass-production volumes /6/.

The Osprey process is a new method for the manufacture of tubes. It involves spray deposition of inert gas atomized molten metal stream on a recipient, Fig. 12.



Manufacture of Tubular Products

① Tundish
② Gas atomizer
③ Spray chamber
④ Material recipient
⑤ Drive
⑥ Product
⑦ Exhaust gas

Fig. 12. Spray deposition of tubular products /13/.

Sandvik Steel in Sweden produces high alloy special steel blanks with dimensions up to 400 mm diameter and up to 8 000 mm in length. The method is interesting because multilayer materials can be produced. Copper could be spray deposited directly on steel tube. This alternative is well worth considering for the production of waste canisters. However, at the present stage it still needs strong development work.

Electroforming is defined as the production of an article by electrodeposition on a mandrel that is subsequently removed. In case the mandrel is not removed the process is called electrodeposition. Electroforming is best suited for producing thin products, such as foil for printed circuit boards. To avoid excessive nodular growth and porosity the deposition rate must be sufficiently slow. A typical value is only 0.03 mm/h /14/. So this appears not to be a suitable production method for canisters with wall thicknesses of 50 or 60 mm.

Radial forging is a process used to reduce the cross-sectional area of the workpiece by typically four radially aligned hammers, as shown in Fig. 13. Between strokes of the hammers the workpiece is rotated and fed in. Tubes are hot forged over a water cooled mandrel (Fig. 14). Radial forging is not widely used for the working of copper since copper is easily extruded. The possible applicability of this method needs further study.

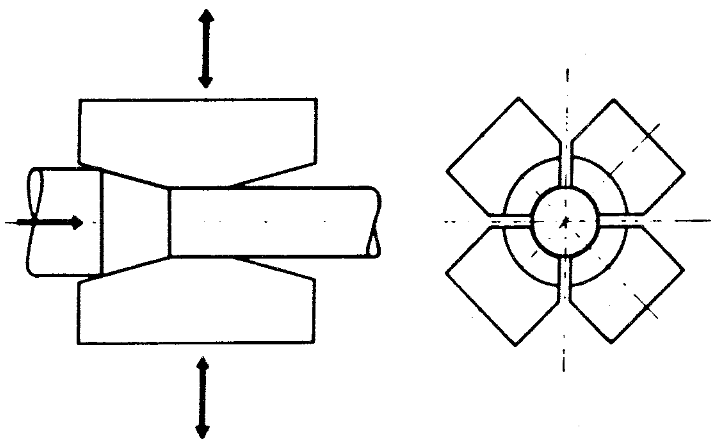


Fig. 13. Four-hammer radial forging /15/.

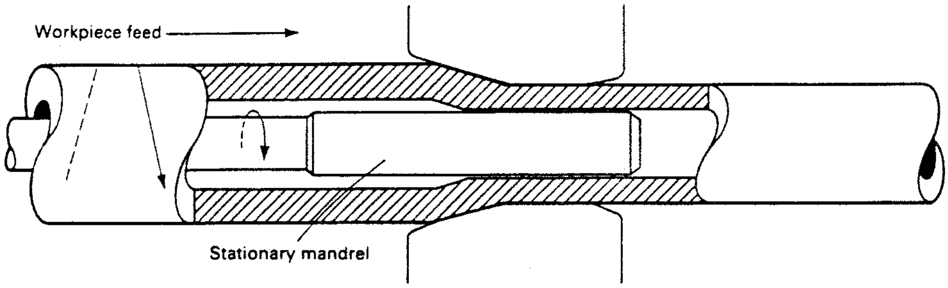


Fig. 14. Radial forging of tube over a mandrel /16/.

4 MANUFACTURING ROUTES AND THEIR COSTS

Three routes are considered as alternatives for the manufacturing of the canisters (Fig. 15). There may appear better alternatives in the future but according to the present knowledge these three manufacturing routes are the most feasible at present and in the near future. The cost estimates of the three routes for various lots of canisters are presented in Appendices 1 - 4.

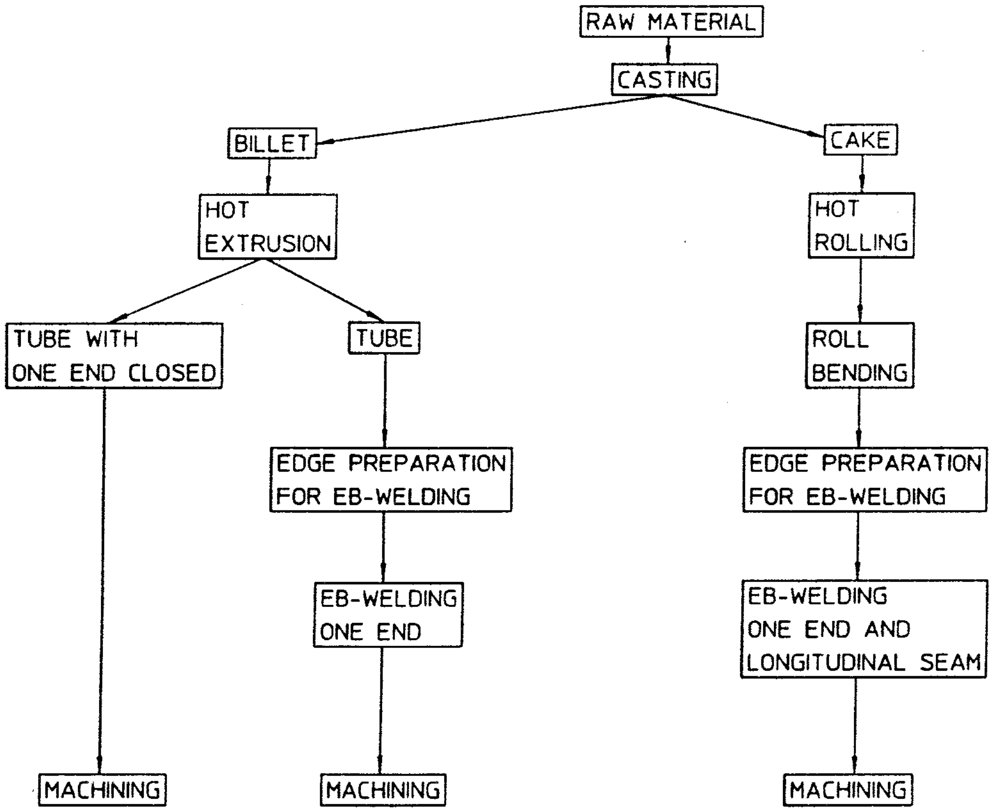


Fig. 15. Alternative manufacturing routes.

4.1 Raw material need and costs

The amount of raw material needed (Table 2) is deduced by taking into account the yield obtained in each manufacturing stage. Most raw material is needed for the extrusion with one end closed and nearly as much is needed for the tube extrusion. The least raw material is clearly consumed by the rolling and bending route, which is thus the most efficient alternative.

Table 2. Raw material need (tons) for canisters extruded both ends open (tube), one end closed (capsule) or produced by rolling and bending (1 = 60 mm wall, 2 = 50 mm wall).

	Tube ext		Capsule ext		Roll & bend	
	1	2	1	2	1	2
Body	10.4	8.7	11.5	9.8	6.4	5.3
Lid(s)	0.92	0.80	0.46	0.40	0.92	0.80
Root support	0.20	0.20	0.10	0.10	0.30	0.30
Weight, total	11.5	9.7	12.1	10.3	7.6	6.4

The cost of the raw material is based on the A-grade copper cathode spot price in the London Metal Exchange (LME) added with 3 %. The addition of 3 % is due to taxes, transportation and storage costs. The spot price of A-grade copper cathodes on April 18, 1991 was 9.90 FIM/kg and the raw material price is thus 10.2 FIM/kg.

Since the yield of some of the processes is low, the amount of scrap is substantial. At least approximately 85 % of all scrap is returned as high quality (not containing impurity particles). Probably the return percent is even higher. The price of the high quality scrap is LME-price minus 0.21 FIM/kg e.g. the scrap price is 9.69 FIM/kg.

4.2 Casting

Some modifications are needed for the casting unit to be able to cast the required sizes of billets. The casting costs are 2.30 FIM/kg. Since such large castings have not been made before some development work is also necessary. These costs were taken into account in the cost estimates.

4.3 Extrusion

The ingot sizes and costs of extrusions are based on the budget estimates given by the manufacturer. According to the manufacturer the ingot weight must be nearly twice the final weight due to extrusion scrap and tolerances, i.e. the yield is only 50 - 55 %. The freight costs are also significant (17 - 23 thousand FIM/canister) since presumably the only extrusion press suitable for this purpose is in the USA.

The estimates for the tubular (both ends open) product are

5	extrusions		37 200	FIM/extrusion
100	"	(1 year)	27 500	"
400	"	(1 year)	26 200	"

For the extrusion with one end closed there is a "Special Tooling" charge (one time) of 185 000 FIM.

The extrusion costs for the tube one end closed are

5	extrusions		41 800	FIM/extrusion
100	"	(1 year)	30 300	"
400	"	(1 year)	27 600	"

4.4 Hot rolling

The hot rolling should be done in a copper hot rolling mill. The nearest copper mills capable of rolling sufficiently wide plate (2600 mm) are in the USSR and in Germany, where the freight is around 4 000 FIM/canister. For this study the costs of hot rolling have been extrapolated from the costs of the hot rolling in a narrow mill to be 1.2 FIM/kg.

If the hot rolling were done in a steel mill the costs would be several times higher (5.8 FIM/kg) due to the capacity losses in the transition period from steel heating and rolling to copper heating and rolling (e.g. heating temperature 800 - 900 °C for copper and 1300 °C for steel).

4.5 Bending

The bending of the hot rolled plate is performed in a three-roll bending machine. From both ends about 2 x thickness, i.e. 100 - 150 mm, remains typically unbent. However, the unbent region can be reduced to about 50 mm by prebending the ends. This method reduces thus the necessary width of the plate and increases the yield so that only 50 mm from each edge of the plate need to be removed. The yield of rolling and bending is then very good, about 95 %. The bending costs are 4 000 FIM/canister according to the manufacturer. The bending costs of the root supports for the lids are estimated to be 300 FIM/root support.

4.6 EB-welding

Electron beam (EB) welding is a good and reliable means of joining thick copper plates. The high quality of the weld seams requires the plate material to be oxygen free copper with machined edges and vacuum operation. The vacuum chamber must be as large as 9 m x 1 m x 1 m, minimum. The operating costs of the EB-welding machine are not high but the start-up costs are significant. A sufficiently large vacuum chamber can be found e.g. in France meaning significant freight costs (8 000 - 12 000 FIM/canister).

The information for the EB-welding costs were obtained from two sources. Both cost estimates for the rolling and bending case were 4 000 - 6 000 FIM/canister for 1 200 - 5 000 canister lots, the costs being somewhat lower in the tube case. For the 5 canister lot the costs/canister are much higher.

4.7 Inspection

In practice, 100 % inspection of the weld seam is not necessary but control of the EB-welding machine and the inspection of the critical regions is sufficient.

There are two viable inspection techniques for the welds in thick copper plates: ultrasonic inspection and radiography.

In the ultrasonic inspection technique echo signals from the material are detected. With optimally set up probes longitudinal, transverse and volume defects can be detected. The observable defect size depends on the ultrasonic frequency as well as grain size of the material and distance from the probe. An advantage is also that ultrasonic inspection is fast and it can easily be automated.

In the radiographic method a special high voltage equipment (>1 MeV) is required due to the thickness of the plate. It should be possible to detect several kinds of defects except crack-like defects running perpendicularly to the inspection direction. Radiography is sensitive but time-consuming.

The exact inspection costs are difficult to estimate before defining e.g. the minimum detectable defect size. For this study the inspection costs using the ultrasonic method are estimated to be 1 000 - 2 000 FIM/canister+lid for the lot size of 1 200 - 5 000. The 5 canister lot requires more manual work and the inspection cost is estimated to be 22 000 FIM/canister+lid.

4.8 Machining

With a tube extruded one end closed only one machining stage is needed in the production of the canisters. The other methods, tube extrusion with both ends open and rolling & bending, require edge preparation by machining before the EB-welding. The final machining can be done alternatively before or after the welding. There may be a need to machine the inner surface after the root supports are removed. The inner diameter tolerances can be easily obtained using a modern machining unit.

The machining costs are according to the manufacturer 9 000 - 10 000 FIM/canister depending on the amount of copper to be machined.

4.9 Lid manufacture and costs

The most optimal way to produce the lids is casting the cake, forging and machining. The casting can be done with the present casting machine at Outokumpu Poricopper Oy without any changes or extra costs. Forging (e.g. hammering at 600 - 800 °C) results in a homogenous, recrystallized grain structure and the desired shape. It's costs are estimated to be 2.5 FIM/kg. The costs of the machining are according to the manufacturer 1 200 FIM/lid. The tolerance requirements (-0/+1 mm) can easily be obtained. Forging results also in a small grain size which makes the inspection of the EB-weld seam easier.

4.10 Root support manufacture and costs

Root supports are most rationally produced by casting a cake, hot rolling, sawing a slice and bending. The root supports for welding the bottom end and the longitudinal seam need not be as thick as the root support for the lid welding and some 20 - 40 mm is sufficient.

The casting costs are 2.3 FIM/kg. The surface quality of the root support is not critical and no surface preparation is needed after milling the hot rolled surface and sawing the pieces. The costs of the these manufacturing stages are estimated to be 2.5 FIM/kg. The bending cost estimate is 300 FIM/root support.

4.11 Total costs

The total costs of the canisters are summarized in Table 3. It is seen that the cost decreases very little for lots of more than 1 200 canisters while a 5 canister lot is substantially more expensive. This is due to the investment costs for the various manufacturing stages. Rolling and bending is the most economical of the three routes: 70-75 % of the cost of the other routes. Tube extrusion route is about 10 000 FIM more expensive than the extrusion with one end closed. The cost of the canister with the 60 mm wall (Case 1) is about 15 - 25 000 FIM more expensive than the canister with the 50 mm wall.

Table 3. Total cost/canister (thousand FIM) for different lot sizes of canisters extruded both ends open (tube), one end closed (capsule) or produced by rolling and bending (1 = 60 mm wall, 2 = 50 mm wall).

Lot size	Tube ext		Capsule ext		Roll & bend	
	1	2	1	2	1	2
5	400	374	418	398	270	253
1200	183	157	172	153	131	115
2400	182	156	171	152	129	113
5000	180	153	168	148	128	111

The estimates of the manufacturing costs of the canisters is based on today's prices. The raw material price and exchange rates may change resulting in cost changes, as well. For example 10 % change in the raw material price results in about 3-5 % change in the total costs for the 1 200 - 5 000 piece lots.

For the 5 canister lot uncertainties exist in the manufacturing costs. The biggest uncertainty is the welding cost. The investments for the support construction are estimated to be 50 000 FIM, but could be higher. However no cost estimates have been obtained. Another source of uncertainty is in the inspection, which depends strongly on the requirements. For the 5 canister lot the inspection is assumed to be done manually with (mainly) existing machines. These costs may be somewhat overestimated. The scrap return may also be higher (e.g. 95 %), which corresponds to about 5 000 FIM saving in the total costs. The lids and root support costs are within ±1 000 FIM. The uncertainty of the total costs for 5 000 canisters is within 15 %.

For the 1 200 - 5 000 canister lot the uncertainties are much smaller than for the 5 canister lot, because the investment costs/canister are not significant. The uncertainty of the cost is 10 %.

One open question is the yield of the process, i.e. how many of the manufactured canisters must be scrapped. Since in practice all the processes are well controlled in the continuous operation and some faults can be corrected (e.g. welding), the yield is probably very high, over 95 %. If one assumes that 5 % is scrapped, the increase in total costs is about 4 000 FIM (~2 - 3 %) for the 1 200 - 5 000 canister lots (since the material is returned).

5 EXPERIENCE FROM MODEL EXTRUSIONS

In order to gain experience of hot extrusion, 1/4-scale model canisters were manufactured. Two sets of canisters were extruded. The first set was extruded directly one end closed. The second set was extruded using the indirect method and the canisters were machined into the final shape.

In the indirect extrusions the billet temperature was about 850 °C. The extrusion was done in the air and the extruded capsule was immersed into water in five minutes after the extrusion. The microstructure was found to be recrystallized with an average grain size of 0.15 mm. Unfortunately this type of extrusion process is not easily applicable to the full size canisters since the length of the backward extrusion is so high (4 400 mm).

The direct extrusions were done into water. The billet temperature was about 850 °C. The wall thickness was 18 mm. A small reduction of the outer diameter was observed in all the extruded capsules near the closed forward end. One of the as-extruded canisters was subjected to microstructural and ultrasonic examination. Also the mechanical properties were examined. The grain structure is recrystallized with an average grain size ranging from 0.1 mm to 0.5 mm. The mechanical properties are typical for hot worked structure.

Both direct and indirect extrusion method result in a sound and recrystallized grain structure in the 1/4 scale prototype canisters.

6 MANUFACTURE OF 1 600 mm DIAMETER CANISTERS

The manufacturing possibilities and cost estimates for 1 600 mm diameter canisters were evaluated. The wall thickness was set to 50 mm. At present it seems that hot rolling, bending and EB-welding the longitudinal seams is the most feasible route. Two 55 x 2 600 x 4 500 mm plates will be bent 180° and welded together by two longitudinal seams. The lids are made of hot rolled 60 x 1 800 x 1 800 mm plate by forging as in the case of smaller lids. The root supports can also be manufactured the same way as the root supports for the smaller canisters.

The costs of each manufacturing stage are based on the cost estimates for the small canisters, except machining costs where a new budget price was quoted. The costs of the large canister manufacture are given in Appendix 5. The estimates are based on the canisters with flat ends. In case of the hemispherical ends the lid costs must be multiplied by 1.7.

ACKNOWLEDGEMENTS

During the course of this work several companies were contacted. We are grateful to

Cooper Industries, Cameron Forged Products Division (USA)
Construction Industrielles de la Mediterranee (France)
The Welding Institute (England)
Rautaruukki Oy (Finland)
Valmet Paper Machinery (Finland)
Outokumpu Poricopper Oy (Finland)

for fruitful co-operation.

Heikki Raiko from Technical Research Centre of Finland acted as a supervising and controlling expert on behalf of TVO and SKB. The contact persons were Jukka-Pekka Salo (TVO), Lars Werme (SKB) and Hannu Rajainmäki (POCO).

REFERENCES

1. Werme L. Near-field performance of the advanced cold process canister. December 1990, Nuclear Waste Commission of Finnish Power Companies, Report YJT-90-20.

2. Salo J.-P., Raiko, H. The copper/steel canister design for nuclear waste disposal. May 1990, TVO/KPA Turvallisuus ja tekniikka, Työraportti 90-10 Rev.1.

3. Sanderson A., Werme L. O. Can high power electron beam welding encapsulate nuclear waste for 100 000 years? The Welding Institute Research Bulletin, November 1986, pp. 365 - 370.

4. Lyman W. S., Servi I. S. Copper availability and cost considerations, Appendix 5, Background studies in support of a feasibility assessment on the use of copper-base materials for nuclear waste packages in a repository in tuff, June 1990, Lawrence Livermore Laboratory. 14 p.

5. Cameron Forge Company Extruded Products, 1988 Cameron Forge Company (Brochure).

6. Kundig K. J. A. Fabrication alternatives for manufacturing copper and copper alloy nuclear waste containers, Appendix 2, Backround studies in support of a feasibility assessment on the use of copper-base materials for nuclear waste packages in a repository in tuff, June 1990, Lawrence Livermore National Laboratory. 45 p.

7. Laue K., Stenger H. Extrusion - Processes, Machinery, Tooling, Metals Park, Ohio, 1981, American Society for Metals. 457 p.

8. Rowell D. R. Large tube production by radial extrusion, 1977 Manufacturing Engineering Transactions, 5th North American Metalworking Research Conference Proceedings, 1977, Society of Manufacturing Engineers, pp. 122-127.

9. The Machining of High-Conductivity Copper, Project Report 343A, International Copper Research Association, 1984.

10. Mantel, W. Kupferwerkstoffe Schweißen für Sonderanwendungen. Maschinenmarkt, Würzburg, 81 (1975) 91, pp. 1816-1818.

11. Steffens H.-D., Sievers E.-R. Festigkeitseigenschaften von Elektronenstrahlschweißverbindungen aus Kupfer bei erhöhten Temperaturen - analytishe Untersuchungen, Schweißen und Schneiden, 43 (1991) Heft 3, pp. 150-154.

12. Stewart J. D., Sr. Tube Spinning, Metals Handbook. 9. ed., Volume 14, Forming and Forging, Metals Park, Ohio, 1988, ASM International. pp. 675-679.

13. Spray Deposition. New Method in Material Technology for Metals - The Osprey Process, 1989, Mannesmann Demag (Brochure).

14. Goodman E. T. J. The manufacture of waveguide components by electroforming. The Post Office Electrical Engrs Jour, 64 (1971) 3, pp. 160-163.

15. Hojas H., Garrett N. I. GFM forging and high-reduction machines, Hot Working and Forming Processes, London, 1980, The Metals Society, pp.259-262.

16. Hojas H. Radial Forging, Metals Handbook. 9. ed. Volume 14, Forming and Forging, Metals Park, Ohio, 1988, ASM International, pp.145-149.

APPENDIX 1

Costs/canister for 5 canisters lot (thousand FIM) extruded both ends open (tube), one end closed (capsule) or produced by rolling and bending (1 = 60 mm wall, 2 = 50 mm wall).

	Tube extr		Capsule extr		Roll & bend	
	1	2	1	2	1	2
Body						
Raw material	106.1	88.7	117.3	100.0	65.3	54.1
Casting	201.9	198.0	204.5	200.5	114.7	112.2
Extrusion	58.2	54.2	101.8	98.8		
Hot rolling					11.6	10.4
Bending					4.0	4.0
Welding	25.0	21.0			33.0	33.0
Inspection	22.0	22.0	22.0	22.0	22.0	22.0
Machining	10.0	10.0	10.0	10.0	9.0	9.0
Body total	**423.2**	**394.0**	**455.6**	**431.3**	**259.6**	**244.7**
Lid(s)						
Raw material	9.4	8.2	4.7	4.1	9.4	8.2
Casting	2.1	1.8	1.1	0.9	2.1	1.8
Forging	2.3	2.0	1.2	1.0	2.3	2.0
Machining	2.4	2.4	1.2	1.2	2.4	2.4
Lids total	**16.2**	**14.4**	**8.1**	**7.2**	**16.2**	**14.4**
Root support						
Raw material	2.0	2.0	1.0	1.0	3.1	3.1
Casting	0.5	0.5	0.2	0.2	0.7	0.7
Hot rolling	0.2	0.2	0.2	0.2	0.2	0.2
Bending	0.6	0.6	0.3	0.3	0.6	0.6
Root s. total	**3.3**	**3.3**	**1.8**	**1.8**	**4.6**	**4.6**
Return scrap						
Body scrap	-38.3	-33.6	-45.8	-40.2	-6.0	-5.5
Rest scrap	-4.0	-4.0	-1.7	-1.7	-4.8	-4.8
Return total	**-42.3**	**-37.6**	**-47.5**	**-41.9**	**-10.8**	**-10.3**
Total	**400**	**374**	**418**	**398**	**270**	**253**

APPENDIX 2

Costs/canister for 1 200 canisters lot (thousand FIM) extruded both ends open (tube), one end closed (capsule) or produced by rolling and bending (1 = 60 mm wall, 2 = 50 mm wall).

	Tube extr		Capsule extr		Roll & bend	
	1	2	1	2	1	2
Body						
Raw material	106.1	88.7	117.3	100.0	65.3	54.1
Casting	24.6	20.7	27.2	23.2	15.1	12.6
Extrusion	48.5	44.5	53.3	50.3		
Hot rolling					11.6	10.4
Bending					4.0	4.0
Welding	15.0	11.0			14.0	14.0
Inspection	2.0	2.0	2.0	2.0	2.0	2.0
Machining	10.0	10.0	10.0	10.0	9.0	9.0
Body total	**206.2**	**176.9**	**209.8**	**185.5**	**121.0**	**106.1**
Lid(s)						
Raw material	9.4	8.2	4.7	4.1	9.4	8.2
Casting	2.1	1.8	1.1	0.9	2.1	1.8
Forging	2.3	2.0	1.2	1.0	2.3	2.0
Machining	2.4	2.4	1.2	1.2	2.4	2.4
Lids total	**16.2**	**14.4**	**8.1**	**7.2**	**16.2**	**14.4**
Root support						
Raw material	2.0	2.0	1.0	1.0	3.1	3.1
Casting	0.5	0.5	0.2	0.2	0.7	0.7
Hot rolling	0.2	0.2	0.2	0.2	0.2	0.2
Bending	0.6	0.6	0.3	0.3	0.6	0.6
Root s. total	**3.3**	**3.3**	**1.8**	**1.8**	**4.6**	**4.6**
Return scrap						
Body scrap	-38.3	-33.6	-45.8	-40.2	-6.0	-5.5
Rest scrap	-4.0	-4.0	-1.7	-1.7	-4.8	-4.8
Return total	**-42.3**	**-37.6**	**-47.5**	**-41.9**	**-10.8**	**-10.3**
Total	**183**	**157**	**172**	**153**	**131**	**115**

APPENDIX 3

Costs/canister for 2 400 canisters lot (thousand FIM) extruded both ends open (tube), one end closed (capsule) or produced by rolling and bending (1 = 60 mm wall, 2 = 50 mm wall).

	Tube extr		Capsule extr		Roll & bend	
	1	2	1	2	1	2
Body						
Raw material	106.1	88.7	117.3	100.0	65.3	54.1
Casting	24.2	20.3	26.8	22.8	14.9	12.4
Extrusion	48.5	44.5	53.3	50.3		
Hot rolling					11.6	10.4
Bending					4.0	4.0
Welding	14.5	10.5			13.0	13.0
Inspection	1.5	1.5	1.5	1.5	1.5	1.5
Machining	10.0	10.0	10.0	10.0	9.0	9.0
Body total	**204.8**	**175.6**	**208.9**	**184.6**	**119.3**	**104.5**
Lid(s)						
Raw material	9.4	8.2	4.7	4.1	9.4	8.2
Casting	2.1	1.8	1.1	0.9	2.1	1.8
Forging	2.3	2.0	1.2	1.0	2.3	2.0
Machining	2.4	2.4	1.2	1.2	2.4	2.4
Lids total	**16.2**	**14.4**	**8.1**	**7.2**	**16.2**	**14.4**
Root support						
Raw material	2.0	2.0	1.0	1.0	3.1	3.1
Casting	0.5	0.5	0.2	0.2	0.7	0.7
Hot rolling	0.2	0.2	0.2	0.2	0.2	0.2
Bending	0.6	0.6	0.3	0.3	0.6	0.6
Root s. total	**3.3**	**3.3**	**1.8**	**1.8**	**4.6**	**4.6**
Return scrap						
Body scrap	-38.3	-33.6	-45.8	-40.2	-6.0	-5.5
Rest scrap	-4.0	-4.0	-1.7	-1.7	-4.8	-4.8
Return total	**-42.3**	**-37.6**	**-47.5**	**-41.9**	**-10.8**	**-10.3**
Total	**182**	**156**	**171**	**152**	**129**	**113**

APPENDIX 4

Costs/canister for 5 000 canisters lot (thousand FIM) extruded both ends open (tube), one end closed (capsule) or produced by rolling and bending (1 = 60 mm wall, 2 = 50 mm wall).

	Tube extr		Capsule extr		Roll & bend	
	1	2	1	2	1	2
Body						
Raw material	106.1	88.7	117.3	100.0	65.3	54.1
Casting	24.0	20.1	26.6	22.6	14.7	12.2
Extrusion	47.2	43.2	50.6	47.6		
Hot rolling					11.6	10.4
Bending					4.0	4.0
Welding	14.0	10.0			12.0	12.0
Inspection	1.0	1.0	1.0	1.0	1.0	1.0
Machining	10.0	10.0	10.0	10.0	9.0	9.0
Body total	**202.3**	**173.0**	**205.5**	**181.2**	**117.6**	**102.7**
Lid(s)						
Raw material	9.4	8.2	4.7	4.1	9.4	8.2
Casting	2.1	1.8	1.1	0.9	2.1	1.8
Forging	2.3	2.0	1.2	1.0	2.3	2.0
Machining	2.4	2.4	1.2	1.2	2.4	2.4
Lids total	**16.2**	**14.4**	**8.2**	**7.2**	**16.2**	**14.4**
Root support						
Raw material	2.0	2.0	1.0	1.0	3.1	3.1
Casting	0.5	0.5	0.2	0.2	0.7	0.7
Hot rolling	0.2	0.2	0.2	0.2	0.2	0.2
Bending	0.6	0.6	0.3	0.3	0.6	0.6
Root s. total	**3.3**	**3.3**	**1.7**	**1.7**	**4.6**	**4.6**
Return scrap						
Body scrap	-38.3	-33.6	-45.8	-40.2	-6.0	-6.0
Rest scrap	-4.0	-4.0	-1.7	-1.7	-4.8	-4.8
Return total	**-42.3**	**-37.6**	**-47.5**	**-41.9**	**-10.8**	**-10.8**
Total	**180**	**153**	**168**	**148**	**128**	**111**

APPENDIX 5

Additional cost estimates (thousand FIM)

	Rolling & bending 1 000 pieces lot 50 mm wall 1 600 mm diameter
Body	
Raw material	108
Casting	24
Hot rolling	21
Bending+machining	25
Welding	31
Inspection	10
Body total	**219**
Lid(s)	
Raw material	33
Casting	7
Rolling	4
Forging	8
Machining	2
Lids total	**54**
Root support	
Raw material	6
Casting	1
Hot rolling	1
Bending	1
Root support total	**9**
Return scrap	
Body scrap	-12
Rest scrap	-9
Return scrap total	**-21**
Total	**261**

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[2]Chalmers Institute of Technology
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[2]Chalmers Institute of Technology

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[1]Conterra AB
[2]Teollisuuden Voima Oy (TVO)
[3]Svensk Kärnbränslehantering AB (SKB)
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[1]MBT Tecnologia Ambiental, CENT, Cerdanyola, Spain
[2]KTH, Dpt. of Inorganic Chemistry, Stockholm, Sweden
[3]VTT, Tech. Res. Center of Finland, Espoo, Finland
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Håkan Sandstedt[1], Curt Wichmann[1], Roland Pusch[2], Lennart Börgesson[2], Bengt Lönnerberg[3]
[1]Tyréns
[2]Clay Technology AB
[3]ABB Atom
August 1991

TR 91-36
Tentative outline and siting of a repository for spent nuclear fuel at the Finnsjön site. SKB 91 reference concept
Lars Ageskog, Kjell Sjödin
VBB VIAK
September 1991

TR 91-37
Creep of OFHC and silver copper at simulated final repository canister-service conditions
Pertti Auerkari, Heikki Leinonen, Stefan Sandlin
VTT, Metals Laboratory, Finland
September 1991